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United States Patent [19]

Kooy et al.

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[45] Date of Patent: *Mar. 21, 2000

[54] JAW AND CIRCULAR COLLIMATOR

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[73] Assignee: Radionics, Inc., Burlington, Mass.

[*] Notice: This patent is subject to a terminal disclaimer.

[21] Appl. No.: 09/135,199

[22] Filed: Aug. 17, 1998

Related U.S. Application Data

[63] Continuation of application No. 08/736,792, Oct. 25, 1996.

[51] Int. Cl.[7] G21K 1/02

[52] U.S. Cl. 378/147; 378/65

[58] Field of Search 378/65, 145, 147, 378/150, 151, 152, 148, 149

[56] References Cited

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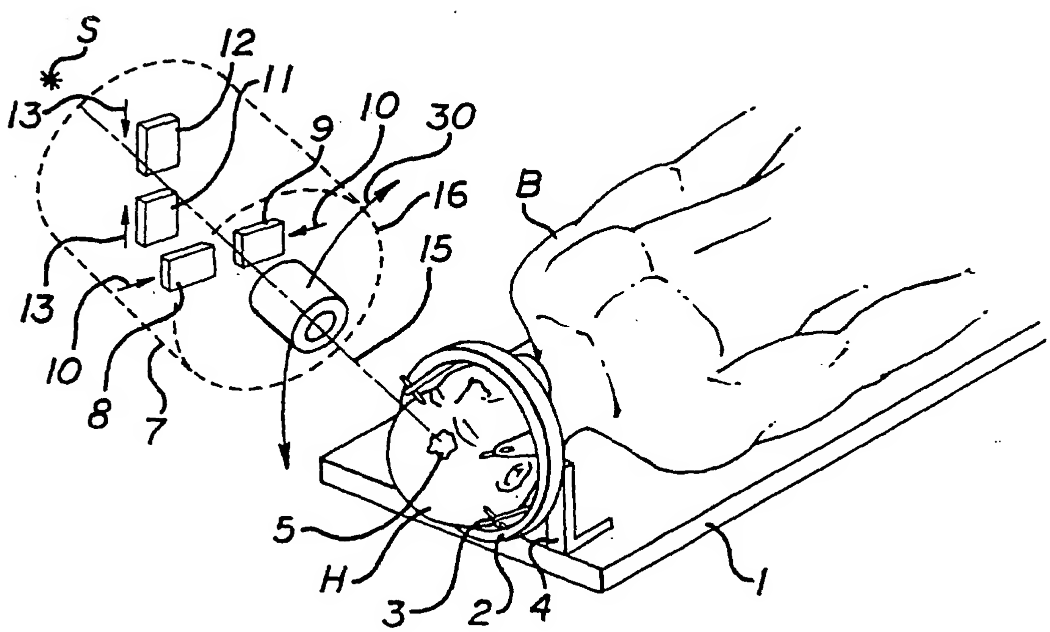
Primary Examiner—David P. Porta
Attorney, Agent, or Firm—Darby & Darby P.C.

[57] ABSTRACT

A collimator apparatus for a treatment planning machine that delivers a beam. A circular collimator defines a circular aperture for the beam. At least one movable collimator jaw is moved into the projection of the circular aperture with respect to the beam in order to eclipse a portion of the beam.

4 Claims, 1 Drawing Sheet



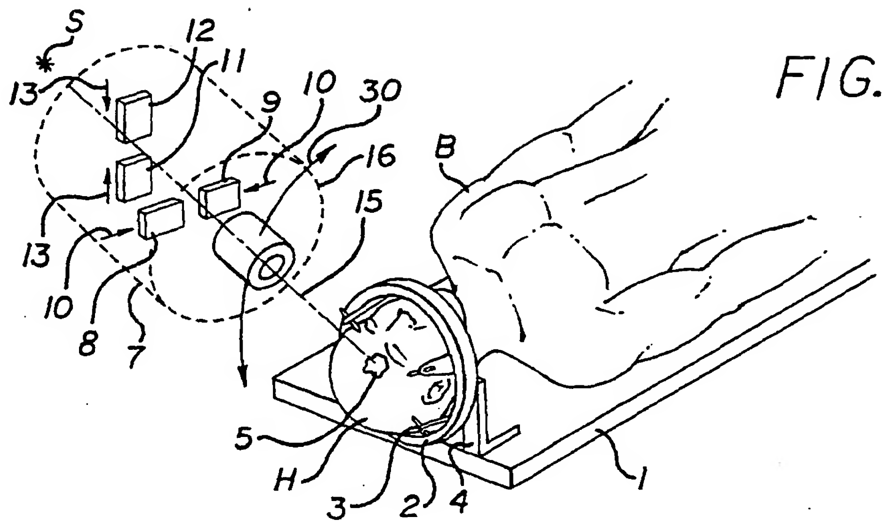


FIG. 1

FIG. 2

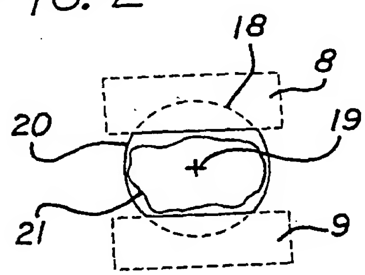


FIG. 3

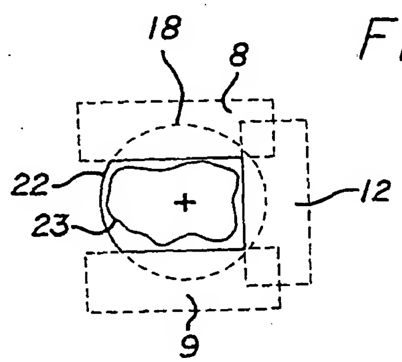
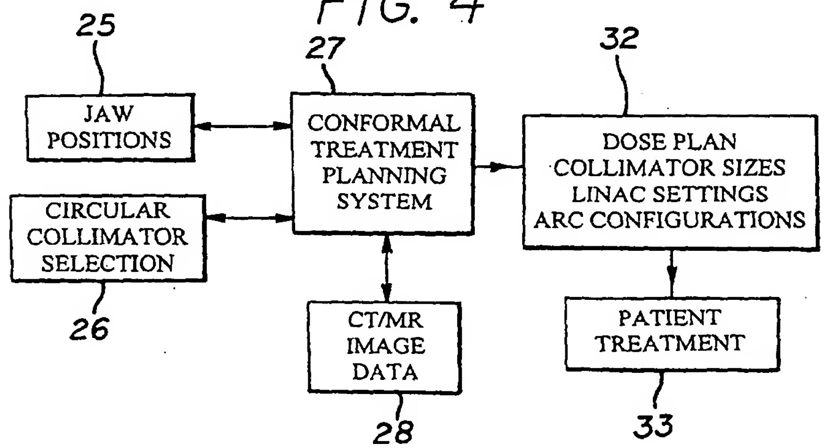


FIG. 4



JAW AND CIRCULAR COLLIMATOR

This application is a continuation of U.S. application Ser. No. 08/736,792, filed Oct. 25, 1996.

BACKGROUND AND SUMMARY OF THE INVENTION

The use of heavy metal collimators of circular shape is now well known for stereotactic radiosurgery using treatment planning machines such as linear accelerators (LINACs) as an X-ray source (see the XKnife information from Radionics, Inc., Burlington, Mass.). Circular collimators are used made of lead or Cerrobend heavy metal with circular apertures of different sizes to collimate the X-ray beams from a LINAC. A collimator is rotated in a so-called gantry angle and couch angle around an isocenter at which position is located a target volume within the body of a patient. Conformal stereotactic radiosurgery involves use of irregularly shaped collimators that are typically non-circular. These may be so-called cut-block collimators, multi-leaf collimators, or miniature multi-leaf collimators (see the information from Radionics, Inc., Burlington, Mass. or Fischer GmbH, Frieburg, Germany). Conformal collimators are usually used in a static mode, meaning static discrete beam directions are determined and different collimators shapes are used depending on the shape of the target volume such as a tumor in the patient's head. Circular collimators are usually used in an arc mode, which means that the circular collimator is swept over the patient's head through the couch and gantry angles. A certain degree of target volume dose shaping is achieved by circular collimator arc therapy, but this is limited because of the limitation in shapes of the circular collimators. More conformal collimation is achieved by the cut-block or multi-leaf changeable shape collimators, but these are complicated devices and are labor intensive to make for a specific patient. In general, the system of the present invention is directed at an improved system for accomplishing conformal arc therapy for LINAC radiosurgery in the body. The system offers a simple and practical way of improving the dose distribution of X-rays for an irregularly shaped target volume by a combination of circular collimators and collimator blocking jaws which can be used to eclipse a portion of the circular beam aperture of the circular collimator.

Heavy metal blocking jaws are typically used in the heads of the linear accelerator to provide large field blocking for standard radiotherapy irradiation of X-rays. Typically, a set of two pairs of opposing jaws orthogonally oriented to each other and moveable in an orthogonal direction to the beam direction are present in the gantry head of a typical X-ray LINAC. These jaws alone are normally not adequate to perform stereotactic radiosurgery. The penumbra effects of use of the four jaws in a LINAC combined with arc therapy would not provide sufficient tightness of radiation for small to medium size brain tumors for instance to be effective for radiosurgery and are typically not employed for such application in radiosurgery. Use of the straight jaw and circular collimator configuration are disclosed herein together with treatment planning software to accommodate its use for conformal arc radiosurgery.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings which constitute a part of the specification, exemplary embodiments exhibiting various objectives and features hereof are set forth, specifically:

FIG. 1 is a diagram of a system in accordance with the present invention.

FIG. 2 shows a beam's-eye view of jaws and circular collimators according to the present invention.

FIG. 3 shows a beam's-eye view of jaws and circular collimators as an alternate embodiment of the present invention.

FIG. 4 shows a process in accordance with the present invention.

DESCRIPTION OF THE INVENTION

The following embodiments illustrate and exemplify the present invention and concept thereof. Yet in that regard they are deemed to afford the best embodiments for the purpose of disclosure and to provide a basis for the claims herein which define the scope of the present invention.

Referring to FIG. 1, a patient's body B lies on a treatment machine couch 1 which is typical for a LINAC. The patient's head H is secured by a stereotactic ring 2 and head posts 3 to the patient's cranium. The ring 2 is immobilized to the LINAC couch by attachments 4. A target volume 5 is shown within the patient's head. A LINAC machine 7 is shown schematically by the dotted outline. Within the gantry of the LINAC are usually a set of blocking jaws which are typical opposing sets of orthogonal jaws, indicated by the pair 8 and 9 which move in the directions indicated by the arrow 10, and jaws 11 and 12, indicated by the arrows 13. A source of X-rays S delivers an X-ray beam with nominal direction indicated by the dashed line 15 converging on the target volume 5. The X-ray beam is defined by the outline of the circular collimator aperture 16 and the position of the jaws 8, 9, 11, and 12 as they intercept the beam profile through the aperture 16. The invention relates to the use, in combination, of circular apertures or other shaped fixed apertures together with blocking jaws in a linear accelerator to provide hybrid shapes of beams which enable better conformal dosimetry towards the target volume.

FIG. 2 gives an example of a so-called "beam's-eye view" of a circular collimator used in conjunction with straight edged jaws in accordance with the present invention. The circular collimator profile is indicated by the dashed outline 18, and the straight edged jaws are illustrated by the dashed area 8 and 9. This view is as seen by the beam looking down the direction of the circular collimator. The nominal beam axis 15 of FIG. 1 is indicated through the point 19 in FIG. 2. The open area between the jaws 8 and 9 and the circular collimator is indicated by the solid line perimeter 20. For an irregularly shaped target volume, indicated by the profile 21, the solid line 20 conforms very much more closely to the target volume than if only the circular collimator 18 were used or, alternatively, if only the jaw configurations 8 and 9 were used. Thus the combination of the circular collimator and straight edged jaws gives much more conformality to a target volume from a given beam direction than the jaws separately or the circular collimators separately.

Referring again to FIG. 1, such a configuration of beam's-eye view profile would then be swept through arcs indicated by the arrows 21 according to the so-called gantry angle and couch angle of a linear accelerator (see the specifications, for example, from Varian Corporation, California, or Siemens Corporation, California, for LINACs).

Referring to FIG. 3 is another embodiment example of the present invention where (with similar numbering as given above) jaws 8 and 9 provide a straight edge perimeter and jaw 12 is one of an orthogonal pair which together with the circular collimator aperture gives rise to a solid line contour 22 that conforms relatively tightly to the tumor profile 23. Here the use of three jaws is invoked to eclipse the circular

aperture 18 to provide better conformality. Other examples may be given of irregularly shaped tumors and one, two, three, or four jaws of the typical four pairs in a LINAC, as illustrated in FIG. 1, can be used to bring in secant type eclipses to the circular collimator shape to provide the best conformality with this combination of apertures. Different size radius collimators 18 could be invoked, depending on the size of the tumor.

In accordance with the present invention and illustrated by FIG. 4, a system and process comprising determination of jaw positions 25 and selection of circular collimators 26 is used in cooperation with a conformal treatment planning system 27 such as the XKnife software and computer workstation of Radionics, Inc., Burlington, Mass. Such a computer workstation will have input data from image scanning of the patient's body 28 from a CT or MRI scanner, and treatment planning of beams and dosimetry can be handled in computer system 27. From this, a selection of jaw configurations in combination with circular aperture sizes can be derived, thus determining the values of jaw position 25 and circular collimator size 26. Once determined for a given arc, the jaws and circles may be fixed and the delivery of an arc with this configuration, such as illustrated by arc 30 in FIG. 1, can give rise to conformal radiation to target volume 5. The jaws may also move as the beam arc is swept over the patient in a more dynamic mode. Thus, a process of treatment planning with jaw and circular arc beams is illustrated. CT image data 28 together with treatment planning system is in accordance with the target volume and appropriate beam positions. Thereby, a selection of jaw positions and circular collimator sizes can be determined together with associated arc therapy. The treatment planning system 27 can also derive the arc positions and the arc lengths as well as X-ray dose to optimize the dosimetry on a target such as 5 in FIG. 1. Dose algorithms can be derived (such as those from XKnife or XPlan of Radionics, Inc., Burlington, Mass.) that can derive dosimetry from such jaw/circular collimator ports with swept LINAC arcs. The results of such dosimetry indicate, according to the present invention, that the quality of the conformality of the dose to the target volume is superior and the degree of radiation to normal tissue outside of the target volume is reduced from the situation where only circular collimators are used or only standard jaw configurations are used independently. Thus the present invention represents an improvement over the dosimetry possible by each of these previously used, independent methods. Since square jaws are existent in most standard linear accelerators, and circular collimators are used in standard radiosurgery, the combination of these two elements when used according to the present invention can give substantially superior radiation dose to a target volume. Once a treatment plan has been derived, the appropriate dose plan, collimator sizes, LINAC settings, and arc configurations can be derived (element 32), and the treatment of the patient can proceed (element 33).

Variations of the present invention may be apparent to those skilled in the art, and the system may take other forms with a multitude of variations. The use of non-circular collimators (aperture 16) can be invoked, and this can be used as cut blocks. The use of non-orthogonal jaws in a LINAC may also be used. A non-conventional set of jaws involving one or more jaw configurations may be used in conjugation with a circular aperture in accordance with the present invention to improve treatment planning. For instance, a special set of extra jaws could be built into the LINAC in conjugation with a circular collimator as a dedicated jaw-circle collimator apparatus. Various dose algorithms may be used to determine the dosimetry for jaws and circular collimators. In view of these considerations, and as will be appreciated by persons skilled in the art, implementations, systems, and processes could be considered broadly and with reference to the claims as set for below.

What is claimed is:

1. A collimator system for a treatment planning machine which delivers a beam comprising:

a. a circular collimator which defines a circular aperture for said beam, said circular aperture being positionally fixed with respect to said beam; and

b. at least one collimator jaw that can be moved into the projection of said circular aperture with respect to said beam so as to eclipse a portion of said beam before it enters said circular aperture;

whereby the combined beam aperture of said circular collimator and said collimator jaw deviates from a circular aperture by the degree that said collimator jaw intersects said projection of said circular aperture with respect to said beam; and

c. a conformal treatment planning system in cooperation with said circular collimator and said at least one collimator jaw to configure said circular collimator and said at least one collimator jaw with respect to a target volume based on input data from a scanner.

2. The collimator system of claim 1 wherein said treatment planning machine is a source of an X-ray beam.

3. The collimator system of claim 1 wherein said at least one collimator jaw comprises one of the standard blocking jaws of a linear accelerator.

4. The collimator system of claim 1 and further comprising a treatment planning computer with software which can plan dosimetry from said collimator system based on the circular aperture, position of said at least one collimator jaw, and orientation of said beam through said collimator system in the direction of said beam when said beam is irradiating a patient.

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United States Patent [19]

Blosser et al.

[11] **Patent Number: 4,739,173**

[45] **Date of Patent: Apr. 19, 1988**

[54] **COLLIMATOR APPARATUS AND METHOD**

[75] Inventors: **Gabe F. Blosser**, Haslett; **Emanuel B. Jemison**, Lansing; **Henry G. Blosser**, East Lansing; **Richard L. Maughan**, Grosse Pointe Park, all of Mich.

[73] Assignee: **Board of Trustees operating Michigan State University**, East Lansing, Mich.

[21] Appl. No.: **896,730**

[22] Filed: **Aug. 15, 1986**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 850,486, Apr. 11, 1986.

[51] **Int. Cl.⁴** **G21K 1/02; G21K 1/04**

[52] **U.S. Cl.** **250/505.1**; 378/152

[58] **Field of Search** .... 250/505.1, 363 SH; 378/147, 150, 152

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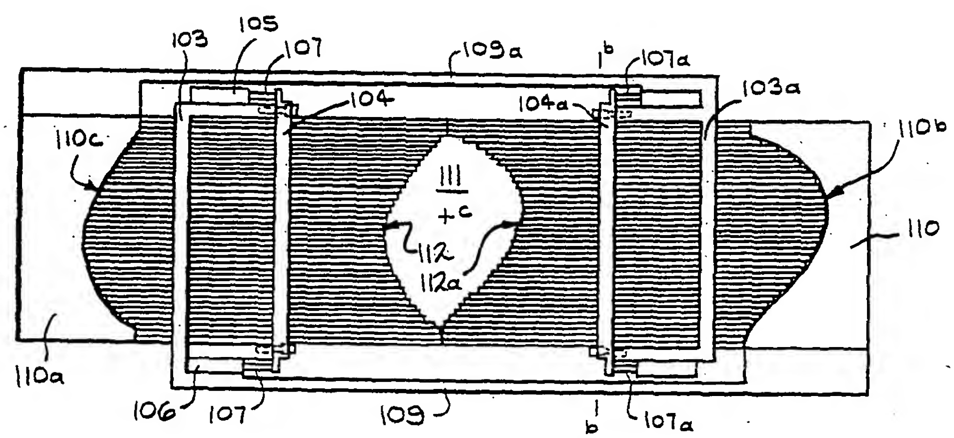
Primary Examiner—Bruce C. Anderson

Attorney, Agent, or Firm—Ian C. McLeod

[57] **ABSTRACT**

A collimator apparatus (**10** or **100**) including one or more bundles of nested rods (**11**, **11*a*** or **101** or **101*a*** or **201**) which define a surface (**112**, **112*a***) which interferes with a beam of radiation is described. The apparatus particularly uses coil spring (**48**) between and along the axis (a—a or c—c) of the rods which are compressed by blocks (**13**, **14**, **13*a*** and **14*a*** or **103**, **104**, **103*a*** and **104*a***) to lock the rods in position in holes in the blocks. The apparatus is particularly useful for shaping radiation beams for patient treatment.

22 Claims, 5 Drawing Sheets



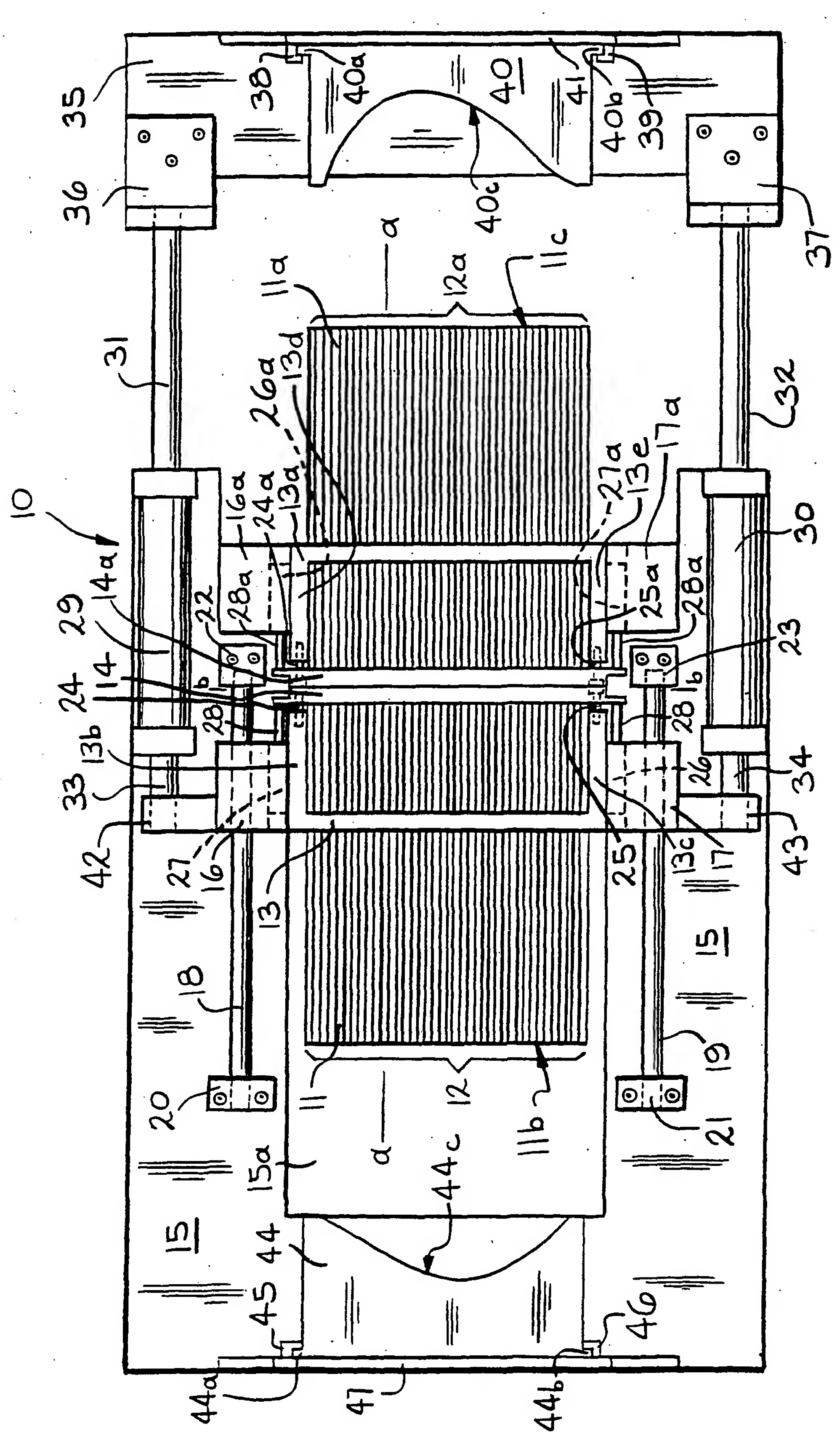

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FIG. 1

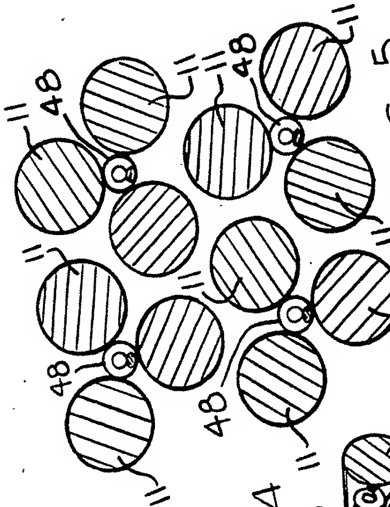

FIG. 5

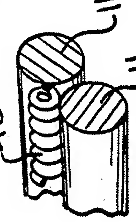

FIG. 4

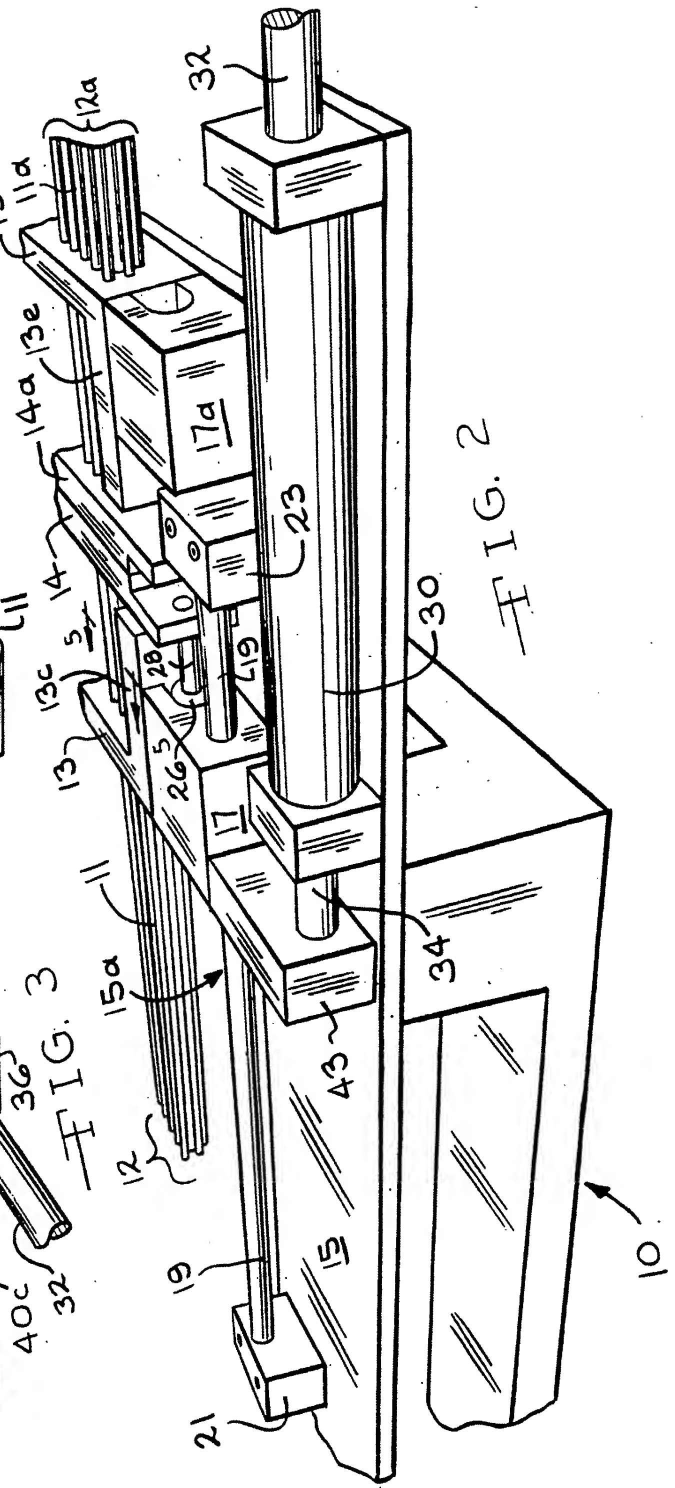

FIG. 2

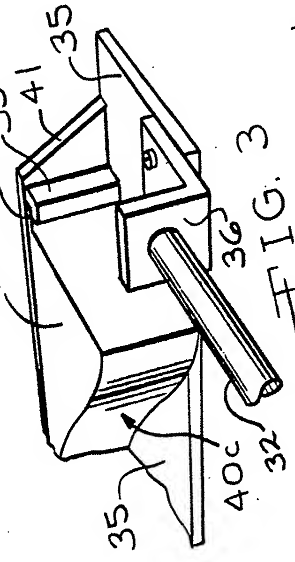

FIG. 3

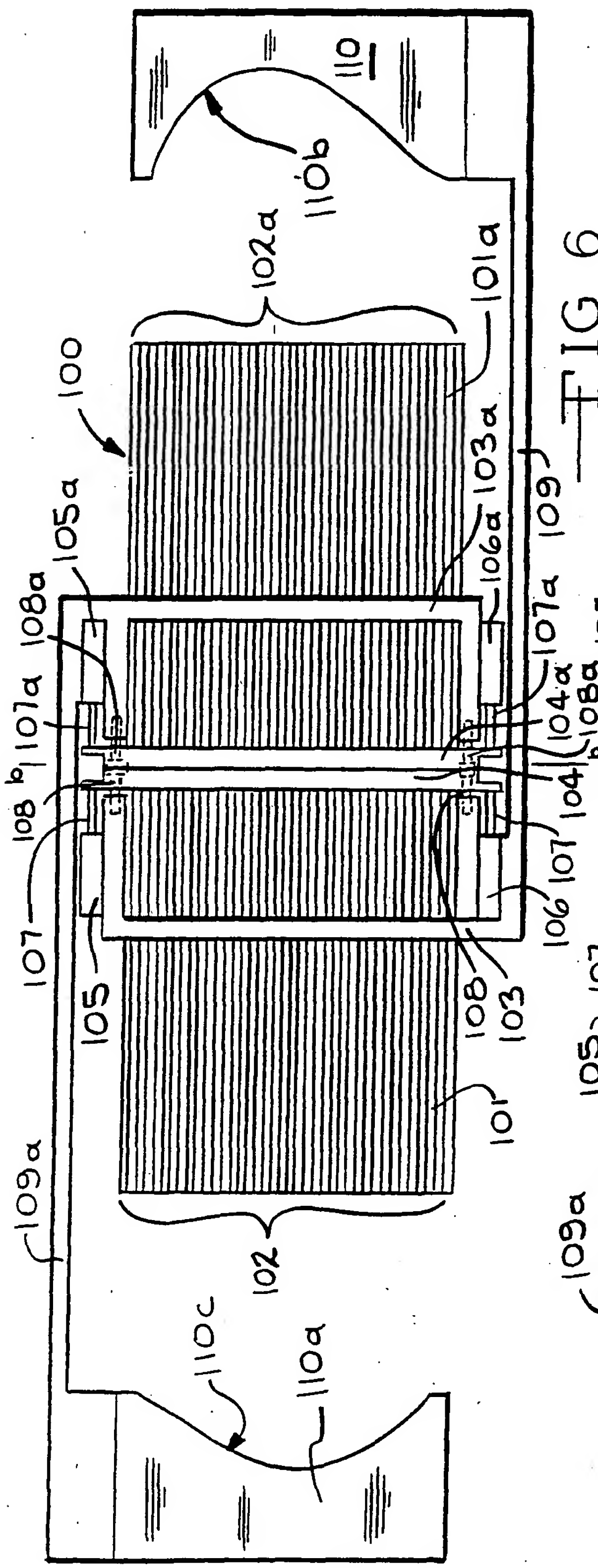
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FIG. 6

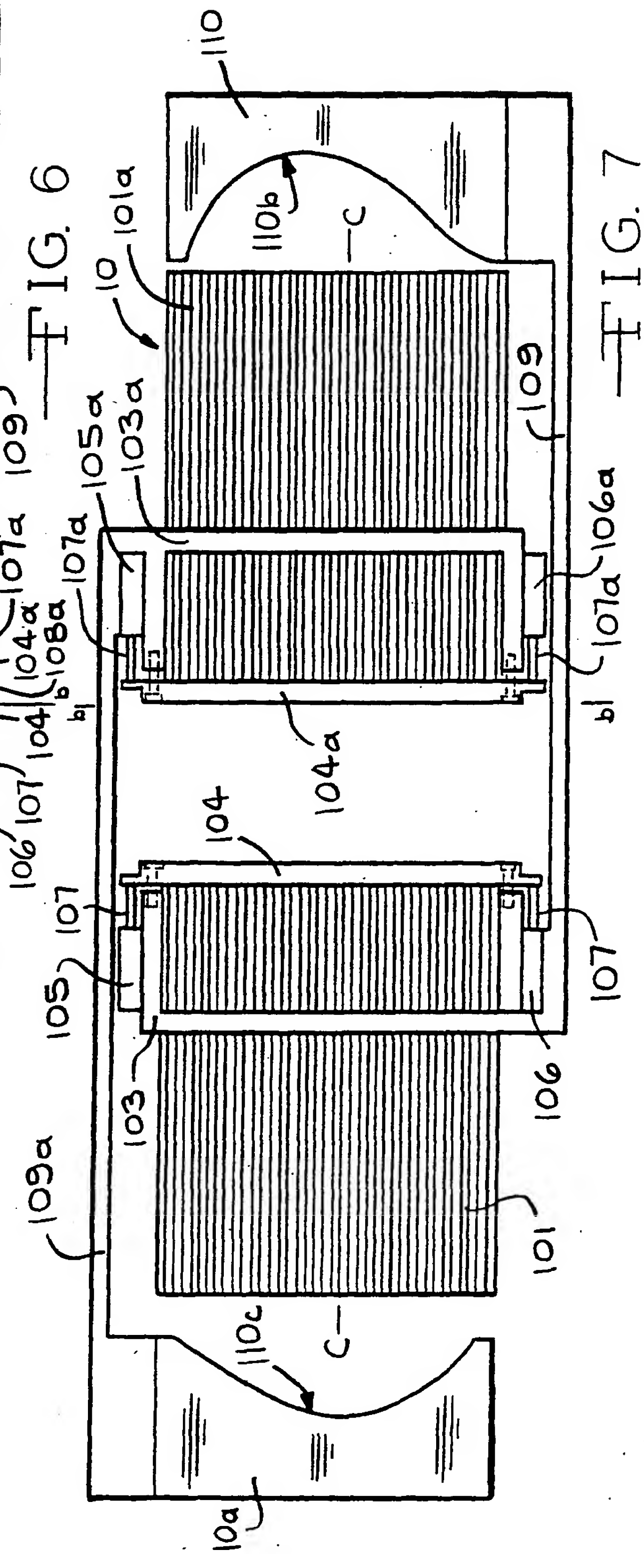
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FIG. 7

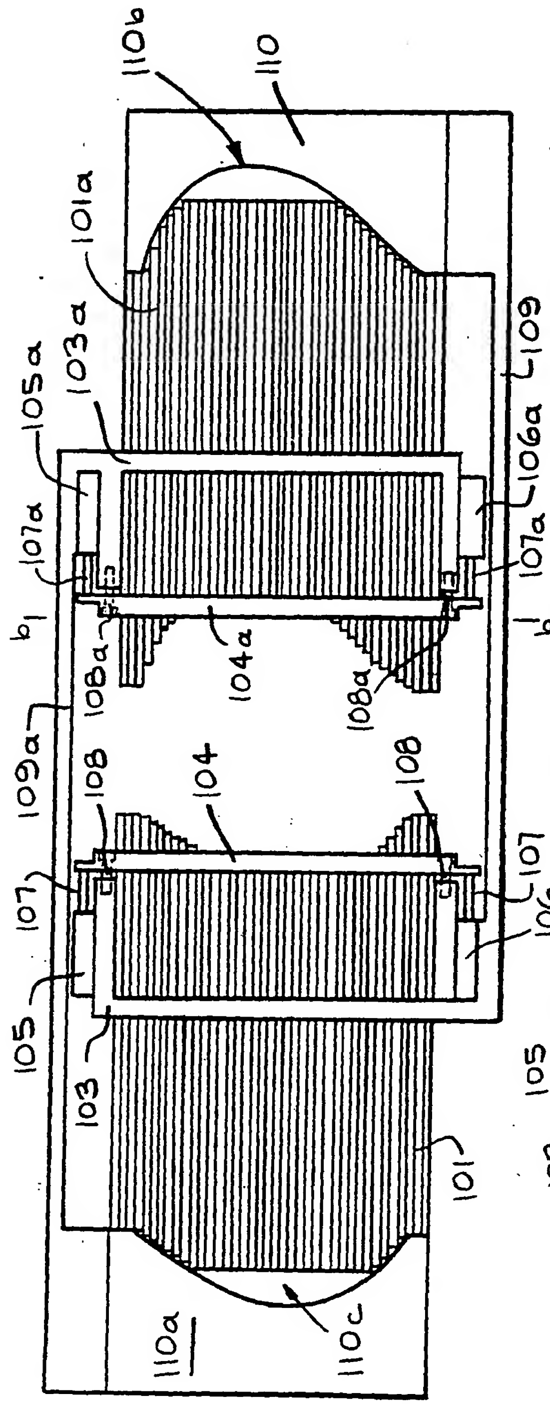

FIG. 8

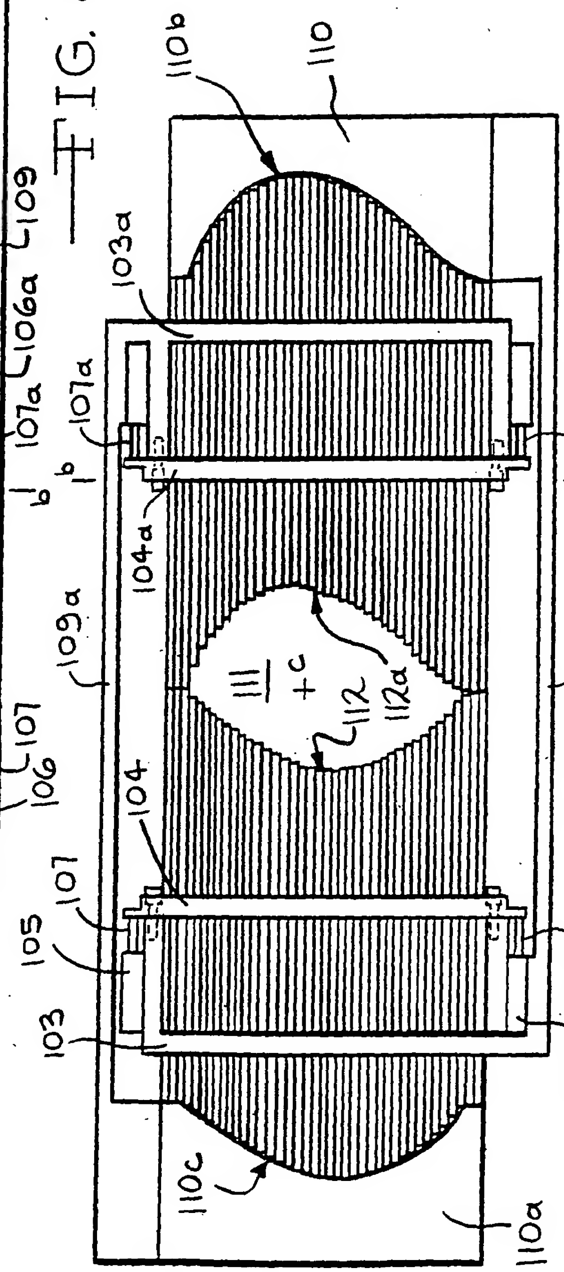

FIG. 9

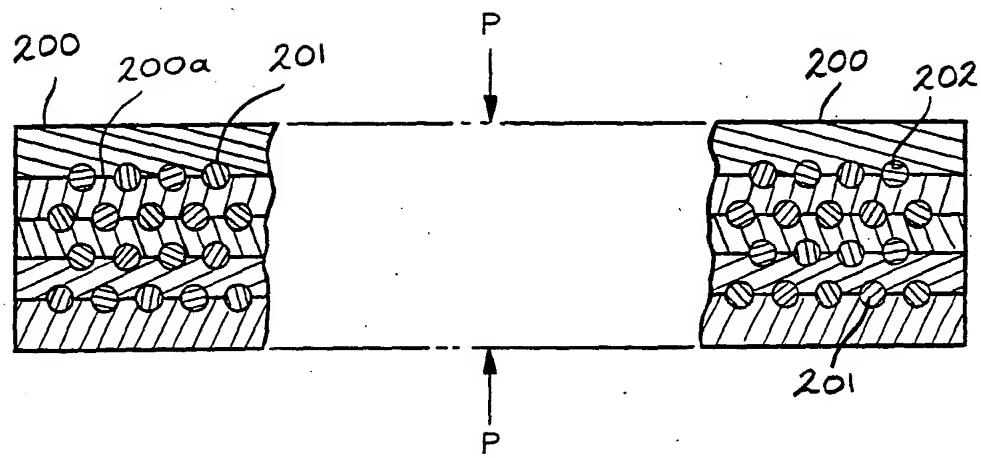

FIG. 10

COLLIMATOR APPARATUS AND METHOD

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U.S. application Ser. No. 850,486, filed Apr. 11, 1986.

BACKGROUND OF THE INVENTION

(1) Summary of the Invention

The present invention relates to an improved collimator apparatus and method for focusing a beam from a radiation source. In particular the present invention relates to an apparatus which uses coil springs for locking nested rods together to define an opening for collimating the beam. Related U.S. application Ser. No. 850,486 describes a collimator apparatus which uses a clamping means to secure nested rods in position. This system works well; however, an improved means for moving and locking the rods to define the opening was needed.

(2) Prior Art

Collimator apparatus for focusing radiation are well known to the prior art. Most of these apparatus provide beams with a fixed cross-section which can be changed only by changing an insert which focuses the beam. This type of apparatus is cumbersome where the cross-section of the beam has to be repeatedly changed such as in patient treatment with radiation directed at a defined area of the body which is changed from patient to patient.

Variable collimator apparatus for radiation are also well known to the prior art. These apparatus provide a moveable interfering member in the beam. U.S. Pat. No. 4,463,266 to Brahme describes a collimator apparatus which uses wedge shaped slabs which move into the beam so as to define the beam. This apparatus is complicated and expensive to build because of the precision of the fit of the wedges relative to each other. Other prior art apparatus include camera or iris type lenses with uniformly change the diameter of the beam and thus are not suitable where the beam is to have an irregular cross-section. One prior art example is described in U.S. Pat. No. 4,534,052 to Milcamps. None of this prior art provides a means for rapidly and simply adjusting the beam cross-section non-uniformly.

OBJECTS

It is an object of the present invention to provide a collimator apparatus with a releasable clamping means which secures rods in blocks to define an irregular shaped opening for the radiation and which when released allows movement of the rods to a new position.

It is further an object of the present invention to provide a collimator apparatus with compressed coil spring means between nested rods for locking the rods together in a manner which insures locking of each rod to define an opening for shaping the cross-section of the radiation and which allows free movement of each rod when unlocked. Further it is an object of the present invention to provide a shaping means for moving the rods when they are unlocked to define the opening. Further still it is an object of the present invention to provide an apparatus which is simple and economical to construct and yet is reliable. Finally it is an object of the present invention to provide a method for using the collimator apparatus. These and other objects will become increasingly apparant by reference to the following description and the drawings.

IN THE DRAWINGS

FIG. 1 is a plan view of the collimator apparatus 10 of the present invention, particularly illustrating nested rods 11 and 11*a* moved together without defining an opening for the radiation.

FIG. 2 is a perspective view in partial section of the apparatus shown in FIG. 1 particularly showing two sets of blocks 13 and 14 and 13*a* and 14*a* journalling two bundles 12 and 12*a* of opposed rods 11 and 11*a*.

FIG. 3 is a partial section perspective view of one shaping member 40 shown in FIG. 1.

FIG. 4 is a partial section perspective view of two rods 11 and a spring 48 which acts to hold the rods 11 together when compressed, when there is a third rod over the spring (not shown).

FIG. 5 is an end cross-sectional view along line 5—5 of FIG. 2 showing the relationship of the springs 48 to the rods 11 such that each rod 11 is locked in position by a spring 48.

FIGS. 6 to 9 are schematic plan views of an apparatus 100 which shows the operation of the apparatus 10 of FIG. 1 and particularly showing a sequence of steps for defining an opening 111, wherein the bundles 102 and 102*a* of rods 101 and 101*a* are moved (FIGS. 6 and 7) and shaped (FIGS. 8 and 9) by the shaping members 110 and 110*a*.

FIG. 10 shows a different block 200 for clamping rods 201 in holes 202.

GENERAL DESCRIPTION

The present invention relates to a collimator apparatus for producing a cross-sectionally shaped beam of radiation from a radiation source which comprises: support plate means having a central opening around a beam axis through which the beam of radiation can pass; a bundle of nested rods mounted adjacent the support plate means each rod being movable into the beam at an angle to the beam axis to interfere with the beam, the rods having first ends which together define a first surface for shaping the beam around the beam axis and opposite ends from the first ends of the rods; a holder means including spaced apart blocks mounted on the support plate, each block having axially aligned holes mounting the rods so that the first surface is defined and the beam is shaped by the first ends of the rod; releasable clamping means engaging the blocks to secure the rods together in the shape defined by the first ends of the rods.

The present invention particularly relates to a collimator apparatus for producing a cross-sectionally shaped beam of radiation from a radiation source which comprises: support plate means having a central opening around a beam axis through which the beam of radiation can pass; a bundle of nested rods mounted adjacent the support plate means each rod being movable into the beam at an angle to the beam axis to interfere with the beam, the rods having first ends which together define a first surface for shaping the beam around the beam axis and opposite ends from the first ends of the rods; a holder means with two spaced apart blocks mounted on the support plate, each block having axially aligned holes mounting the rods so that the first surface is defined and the beam is shaped by the first ends of the rods and at least one block being movable relative to the other block; releasable clamping means

mounted on the support plate means and engaging the rods between the first and second ends to secure the rods together in the shape defined by the first ends f the rods, wherein th releasable clamping means includes the two spaced apart blocks and multiple coil spring means which have opposed ends which engage the blocks and which are positioned and mounted between the rods so that when at least one of the blocks is moved on the rods towards the other block the coil spring means is compressed and engages the rods surrounding the spring means to clamp the surrounding rods together and wherein the clamping means includes drive means mounted on the holder means and connected to at least one of the blocks for moving the blocks together to compress the coil spring against the rods to prevent movement of the rods in the holes in the blocks and for moving the blocks apart to release the spring means from the rods to allow movement of the rods in the holes in the blocks.

In particular the present invention relates to a collimator apparatus for producing a cross-sectionally shaped beam of radiation from a radiation source which comprises: support plate means having a central opening around a beam axis through which the beam of radiation can pass; a bundle of nested metal rods mounted adjacent the support plate means each rod having a longitudinal axis perpendicular to the beam axis and having first ends which together define a first surface for shaping the beam around the beam axis and opposite ends from the first ends; a holder means with two spaced apart blocks mounted adjacent the support plate means each block having axially aligned holes mounting the rods; rod shaping means adjacent the opposite ends of the rods, wherein the rod shaping means has a second surface corresponding to the first surface which defines varying positions of the first ends of the rods so that the first surface is defined and the beam is shaped by the first ends of the rods; and releasable clamping means engaging the blocks for securing the rods together in the shape defined by the shaping means, wherein the releasable clamping means includes the two spaced apart blocks and including multiple coil spring means which have opposed ends which engage the blocks and which are positioned and mounted between the rods so that when the blocks are moved on the rods towards each other the coil spring means are compressed and engage the rods surrounding each of the spring means to clamp the surrounding rods together and wherein the clamping means includes drive means mounted on the holder means and connected to one of the blocks for moving the blocks together to compress the coil spring means against the rods to prevent movement of the rods in the holes in the blocks and for moving the blocks apart to release the spring means from the rods to allow movement of the rods in the holes.

The present invention also relates to a method for producing a cross-sectionally shaped beam of radiation from a radiation source which comprises providing a collimator apparatus which comprises providing support plate means having a central opening around a beam axis through which the beam of radiation can pass; a bundle of nested rods mounted adjacent the support plate means each rod being movable into the beam at an angle to the beam axis to interfere with the beam, the rods having first ends which together define a first surface for shaping the beam around the beam axis and opposite ends from the first ends of the rods; a holder means with two spaced apart blocks mounted adjacent the support plate, each block having axially aligned holes mounting the rods so that the first surface is defined and the beam is shaped by the first ends of the rods; releasable clamping means mounted on the support plate means and engaging the blocks to secure the rods together in the shape defined by the first ends of the rods; moving the rods in the holes in the block to define the first surface; and clamping the rods with the releasable clamping means.

A primary improvement in the present invention is the use of a coil spring between rods to lock them in position. Also the single rapid reset of the rods without rotation of the position of the rods as described hereinafter is an improvement. The following specific description shows how this is accomplished.

SPECIFIC DESCRIPTION

FIGS. 1 to 5 show the improved collimator apparatus 10 of the present invention. Rods 11 and 11*a* are provided in bundles 12 and 12*a* parallel to axis a—a with one of the ends of the bundle 12 and 12*a* facing each other. The rods 11 and 11*a* are mounted through axially (a—a) aligned holes 14*c* (FIG. 5) in blocks 14 and 14*a* and are parallel to each other. The blocks 14 and 14*a* are mounted perpendicular to the rods 11 and 11*a*. The blocks 13 and 13*a* are parallel to blocks 14 and 14*a* and also have holes (not shown). The blocks 13, 13*a*, 14 and 14*a* are mounted on support plate 15 which has a rectangular opening 15*a*. The blocks 13 and 13*a* are U-shaped such that perpendicular legs 13*b* and 13*c* and 13*d* and 13*e* are facing each other in the plane of the rods 11 and 11*a*. Journal members 16 and 17 which are mounted on the outside of legs 13*b* and 13*c* are movable on spaced apart parallel slides 18 and 19. Support members 16*a* and 17*a* are secured to the support plate 15 and position the block 13*a*. Support plate 15 is bolted to a radiation source, e.g. a cyclotron or x-ray unit. The slides 18 and 19 are secured to the support member 15 by means of mounting members 20, 21, 22 and 23. The blocks 14 and 14a are each movable relative to the blocks 13 and 13*a* towards the respective legs 13*b* and 13*c* and 13*d* and 13*e*. The blocks 14 and 14*a* are guided for movement on pins 24 and 25 and 24*a* and 25*a*. The block 14 is moved by means of power cylinders 26 and 27 mounted inside journal members 16 and 17 adjacent legs 13*b* and 13*c*. The block 14*a* is moved by cylinders 26*a* and 27*a* mounted inside journal members 16*a* and 17*a*. Each cylinder 26, 26*a*, 27 and 27*a* has an arm 28 or 28*a* which is connected to the blocks 14 or 14*a* to provide the movement. Movement of the arms 28 or 28*a* towards the cylinder 26 and 27 or 26*a* and 27*a* moves the blocks 14 and 14*a* towards the block 13 or 13*a* along the rods 11 or 11*a*. As will be seen hereinafter, this construction provides a means for clamping the rods 11 and 11*a* in a predetermined position.

Movement of the bundle 12 and 12*a* of rods 11 and 11*a* is accomplished by means of cylinders 29 and 30 mounted on support member 15 using arms 31 and 32 and 33 and 34. The distal ends of the arms 31 and 32 are secured to a movable end plate 35 by means of brackets 36 and 37. A pair of spaced apart slotted blocks 38 and 39 are mounted on a backing plate 41 and support a shaping member 40 which has two projections 40*a* and 40*b* which slide into slotted blocks 38 and 39. The arms 33 and 34 are mounted on extensions 42 and 43 from journal members 16 and 17. Thus as can be seen the blocks 13 and 14 supporting rods 11 as bundles 12 move

as a unit along with journaled m mbers 16 and 17, extensions 42 and 43, arms 31, 32, 33 and 34 and end plate 35.

Opposite the shaping member 40 is a second shaping member 44 mounted by second slotted blocks 45 and 46 mounted on a second backing plate 47. Projections 44*a* and 44*b* slide into sloted blocks 45 and 46. Each of the shaping members 40 and 44 has a surface 40*c* or 44*c* which faces the ends 11*b* and 11*c* of the bundles 12 and 12*a* respectively. Movement of the bundles 12 and 12*a* of rods 11 and 11*a* so that the ends 11*b* and 11*c* encounter the surfaces 40*c* and 44*c* defines and shapes an opening (see opening 111 in FIG. 9).

As shown in FIGS. 4 and 5 a spring 48 is provided in between each set of three rods 11 (and 11*a*) such that each rod is in contact with a spring 48. The spring 48 extends between blocks 13 and 14 (and between blocks 13*a* and 14*a*) in its uncompressed form such that the springs 48 can then be compressed by the blocks 13 and 14 or 13*a* and 14*a*. Upon movement of the block 14 towards arms 13*b* and 13*c* by cylinders 26 and 27, each spring 48 is compressed and expands and bends to fill the void between the three rods 11 thus locking the rods 11 in position on the blocks 13 and 14. In a similar manner the rods 11*a* are locked by blocks 13*a* and 14*a*. Thus the springs 48 provide a unique one step sequence for locking the rods 11 and 11*a* in position.

FIGS. 6 to 9 show step by step views of the operation of a collimator apparatus 100 similar to the apparatus 10 shown in FIG. 1. The support plate 15 does not have to be rotated to position the rod 101 and 101*a* and bundles 102 and 102*a* as in the collimator apparatus shown in Ser. No. 850,486 referred to above. As can be seen from FIGS. 6 to 9, the right hand block 104*a* remains fixed along line b—b. As in FIGS. 1 to 5, rods 101 and 101*a* are in bundles 102 and 102*a* and secured by blocks 103 and 104 and 103*a* and 104*a* and by springs 48 (such as shown in FIGS. 4 and 5). The blocks 103 and 104 (or 103*a* or 104*a*) are moved together by means of cylinders 105 and 106 or 105*a* and 106*a* using arms 107 and 107*a*. The blocks 104 and 104*a* are movably secured to blocks 103 and 103*a* by means of pins 108 or 108*a*. The blocks 103 and 104 are moved along axis c—c by extension 109. Attached to each extension 109 and 109*a* are shaping members 110 and 110*a* with inner surfaces 110*b* and 110*c* which face the bundle of rods 102 and 102*a*.

As shown in FIGS. 7 and 8, the rods 101 are moved towards the surfaces 110*c* of the respective shaping member 110*a*. At the same time, surface 110*b* of shaping member 110 moves towards rods 101*a*. The ends of the rods 101 and 101*a* conform to the shaping members 110 and 110*a* by moving extension 109 towards shaping member 110*a*. As shown in FIG. 9, the blocks 103 and 104 and 103*a* and 104*a* are then moved together and the rods 101 and 101*a* are clamped in position after the opening 111 is formed.

As can be seen from FIGS. 6 to 9, the extension 109 moves shaping member 110 into rods 101*a*. The blocks 103 and 104 on the extension 109 moves the rods 101 into shaping member 110*a*. Thus the opening 111 is defined by movement of the bundles 102 and 102*a* of rods 101 and 101*a* against the shaping members 110 and 110*a*.

The rods 101 and 101*a* in bundles 102 and 102*a* preferably have longitudinal axes which are offset from each other about ½ a rod diameter. This prevents abutting rods 101 or 101*a* from being pushed through the blocks 104 or 104*a* during resetting to the position as shown in FIG. 6. This is accomplished by moving the extension 109 to the right as shown in the drawing so that the r ds are all in the FIG. 6 position as a preliminary step to reforming a new opening 111.

As used herein the term "nested" means that the rods which define the first surface or opening are close to each other preferably on a spacing between the rods of no more than about 0.2 mm. Circular cross-sectioned rods 11 and 11*a* or 101 and 101*a* are preferred in order to provide ease of machining of the holes in blocks 13, 14, 13*a* and 14*a* or 103, 103*a*, 104 and 104*a*. The rods preferably have a cross-section between about 3 and 5 mm. The rods can also have a polygonal cross-section. The rods are generally made of tungsten or stainless steel but other materials with good radiation absorption characteristics can also be used.

The rod shaping member 40, 44 or 110 and 110*a* is preferably composed of polystyrene because it is easily cut into a desired shape of the surface 40*c*, 44*c*, or 110*b*, 110*c* using a hot wire or the like. Other materials can be used so long as they can be shaped.

FIG. 10 shows an alternative block 200 for securing rods 201 in holes 202. The block 200 has spaces 200*a* between the rods 201 such that pressure P applied to the block 200 produces clamping. This releasable clamping means is not as reliable as that of FIGS. 1 to 9.

As will be apparent, the rods 11 or 11*a* and 101 and 101*a* can be moved into position by any means. A shaping member (not shown) defining the shape of the opening 111 as described in Ser. No. 850,486 can be used. It is intended that the foregoing description be only illustrative of the present invention.

We claim:

1. A collimator apparatus for producing a cross-sectionally shaped beam of radiation from a radiation source which comprises:

(a) support plate means having a central opening around a beam axis through which the beam of radiation can pass;

(b) a bundle of nested rods mounted adjacent the support plate means each rod being movable into the beam at an angle to the beam axis to interfere with the beam, the rods having first ends which together define a first surface for shaping the beam around the beam axis and opposite second ends from the first ends of the rods;

(c) a holder means including spaced apart blocks mounted on the support plate, each block having axially aligned holes mounting the rods so that the first surface is defined and the beam is shaped by the first ends of the rods; and

(d) releasable clamping means for moving the blocks so that the blocks or means between the blocks adjacent the rods are in engagement with the rods to secure the rods together in the shape defined by the first ends of the rods.

2. The apparatus of claim 1 wherein the blocks can be compressed together around the rods by the clamping means to reduce the diameter of the holes and thus secure the rods together.

3. The apparatus of claim 1 wherein coil springs are provided between the rods and blocks which can be compressed by moving the blocks along the rods towards each other to hold the rods in position and can be uncompressed to release the rods.

4. A collimator apparatus for producing a cross-sectionally shaped beam of radiation from a radiation source which comprises:

(a) support plate means having a central opening around a beam axis through which the beam of radiation can pass;

(b) a bundle of nested rods mounted adjacent the support plate means each rod being movable into the beam at an angle to the beam axis to interfere with the beam, the rods having first ends which together define a first surface for shaping the beam around the beam axis and opposite second ends from the first ends of the rods;

(c) a holder means with two spaced apart blocks mounted on the support plate, each block having axially aligned holes mounting the rods so that the first surface is defined and the beam is shaped by the first ends of the rods and at least one block being movable relative to the other block;

(d) releasable clamping means mounted on the support plate means and engaging the blocks and rods between the first and second ends to secure the rods together in the shape defined by the first ends of the rods, wherein the releasable clamping means includes multiple coil spring means which have opposed ends which engage the blocks and which are positioned and mounted between the rods so that when at least one of the blocks is moved on the rods towards the other block and coil spring means is compressed and engages the rods surrounding the spring means to clamp the surrounding rods together and wherein the clamping means includes drive means mounted on the holder means and connected to at least one of the blocks for moving the blocks together to compress the coil spring against the rods to prevent movement of the rods in the holes in the blocks and for moving the blocks apart to release the spring means from the rods to allow movement of the rods in the holes in the blocks.

5. The collimator apparatus of claim 4 wherein there are two opposed bundles of rods mounted on the support plate means with the first ends opposite each other and axially displaced relative to each other.

6. The collimator apparatus of claim 4 wherein the rods are circular in cross-section and have a diameter of between about 1 mm and 10 mm.

7. The collimator apparatus of claim 4 wherein rods have a composition for interfering with a neutron beam.

8. The collimator apparatus of claim 4 wherein the rods have a composition for interference with a photon beam.

9. A collimator apparatus for producing a cross-sectionally shaped beam of radiation from a radiation source which comprises:

(a) support plate means having a central opening around a beam axis through which the beam of radiation can pass;

(b) a bundle of nested metal rods mounted adjacent the support plate means each rod having a longitudinal axis perpendicular to the beam axis and having first ends which together define a first surface for shaping the beam around the beam axis and opposite second ends from the first ends;

(c) a holder means with two spaced apart blocks mounted adjacent the support plate means each block having axially aligned holes mounting the rods;

(d) rod shaping means adjacent the opposite second ends of the rods, wherein the rod shaping means has a second surface corresponding to the first surface which defines varying positions of the first ends of the rods so that the first surface is defined and the beam is shaped by the first ends of the rods; and

(e) releasable clamping means engaging the blocks for securing the rods together in the shape defined by the shaping means, wherein the releasable clamping means includes multiple coil spring means which have opposed ends which engage the blocks and which are positioned and mounted between the rods so that when the blocks are moved on the rods towards each other the coil spring means are compressed and engage the rods surrounding each of the spring means to clamp the surrounding rods together and wherein the clamping means includes drive means mounted on the holder means and connected to one of the blocks for moving the blocks together to compress the coil spring means against the rods to prevent movement of the rods in the holes in the blocks and for moving the blocks apart to release the spring means from the rods to allow movement of the rods in the holes.

10. The collimator apparatus of claim 9 wherein there are two opposed bundles of rods mounted on the support plate means with the first ends opposite each other and with the opposed rods having parallel longitudinal axis offset from each other on the axis.

11. The collimator apparatus of claim 9 wherein the rods are circular in cross-section and have a diameter of between about 1 mm and 10 mm.

12. The collimator apparatus of claim 9 wherein the metal composition of the rods is selected from the group consisting of tungsten and stainless steel.

13. The collimator apparatus of claim 9 wherein the rod shaping means is composed of polystyrene foam which is mounted on the holder means.

14. The collimator apparatus of claim 9 wherein the rods have a composition for interference with a neutron or photon beam.

15. The collimator apparatus of claim 9 wherein the rods have a polygonal cross-section.

16. The collimator apparatus of claim 9 wherein the rods have a circular cross-section and wherein the rod shaping means is composed of a polystyrene foam.

17. The apparatus of claim 9 wherein there are two opposed bundles of rods and blocks mounted on the support plate means with the first ends opposite each other and with the opposed rods having parallel longitudinal axis and wherein one bundle of rods and blocks is movable relative to the other bundle of rods and blocks so that the bundle of rods is shaped by a first shaping means, and wherein a second rod shaping means is movable with the movable bundle of rods and blocks to engage the opposite ends of the rods so that the first surfaces are defined and wherein motive means is provided on the support plate means to move the movable bundle of rods, and blocks and second rod shaping means.

18. The apparatus of claim 17 wherein the movable bundle of rods, blocks and shaping means are moved by an arm of a hydraulic or pneumatic cylinder as the motive means which is mounted on the support plate means.

19. The method for producing a cross-sectionally shaped beam of radiation from a radiation source which comprises:

(a) providing a collimator apparatus which comprises support plate means having a central opening

around a beam axis through which the beam of radiati n can pass; a bundle of nested rods mounted adjacent the support plate means each rod being movable into the beam at an angle to the beam axis to interfere with the beam, the rods having first ends which together define a first surface for shaping the beam around the beam axis and opposite second ends from the first ends of the rods; a holder means including spaced apart blocks mounted on the support plate, each block having axially aligned holes mounting the rods so that the first surface is defined and the beam is shaped by the first ends of the rods and at least one block being movable relative to the other block; releasable clamping means engaging the rods between the first and second ends to secure the rods together in the shape defined by the first ends of the rods, wherein the releasable clamping means includes multiple coil spring means which have opposed ends which engage the blocks and which are positioned and mounted between the rods so that when at least one of the blocks is moved on the rods towards the other block the coil spring means is compressed and engages the rods surrounding the spring means to clamp the surrounding rods together and wherein the clamping means includes drive means mounted on the holder means and connected to one of the blocks for moving the blocks together to compress the coil spring against the rods to prevent movement of the rods in the holes in the blocks and for moving the blocks apart to release the spring means from the rods to allow movement of the rods in the holes in the blocks;

(b) moving the rods in the holes in the blocks so that the rods define the first surface;

(c) clamping the rods with the releasable clamping means by moving the blocks so that the spring means is compressed to prevent movement of the rods; and

(d) producing the shaped beam defined by the first ends of the rods.

20. The method for producing a cross-sectionally shaped beam of radiation from a radiation source which comprises:

(a) providing a collimator apparatus which comprises support plate means having a central opening around a beam axis through which the beam of radiation can pass; a bundle of nested metal rods mounted on the support plate means each rod having a longitudinal axis perpendicular to the beam axis and having first ends which together define a first surface for shaping the beam around the beam axis and opposite second ends from the first ends; a holder means with two spaced apart blocks mounted on the support plate each block having axially aligned holes mounting the rods; rod shaping means adjacent the opposite second ends of the rods, wherein the rod shaping means has a second surface corresponding to the first surface which defines varying positions of the first ends of the rods so that the first surface is defined and the beam is shaped by the first ends of the rods; and releasable clamping means for securing the rods together in the shape defined by the shaping means, wherein the releasable clamping means includes multiple coil spring means which have opposed ends which engage the blocks and which are positioned and mounted between the rods so that when the blocks are moved on the rods towards each other the coil spring means is compressed and engages the rods surrounding the spring means to clamp the surrounding rods together and wherein the clamping means includes drive means mounted on the holder means and connected to at least one f the blocks for moving the blocks together to compress the coil spring against the rods to prevent movement of the rods in the holes in the blocks and for moving the blocks apart to release the spring means from the rods to allow movement of the rods in the holes;

(b) moving the opposite rods in the holes in the blocks with the second ends against the rod shaping means to define the first surface;

(c) clamping the rods with the releasable clamping means by moving the blocks so that the spring means is compressed to prevent movement of the rods; and

(d) producing the shaped beam defined by the first ends of the rods.

21. The method of claim 20 wherein there are two bundles of rods and blocks each with a rod shaping means mounted on the support plate means with the first ends opposite each other and with the opposed rods having parallel longitudinal axis offset from each other wherein one bundle of rods and blocks are movable together relative to the other bundle of rods and blocks and wherein one bundle of rods and blocks is moved relative to the other bundle of rods and blocks so that the one bundle of rods is shaped by a first of the shaping means and wherein a second rod shaping means is moved with the movable bundle of rods so that the opposite second ends of the rods in the other bundle of rods engages a second of the rod shaping means so that the first surfaces are defined for each of the bundles of rods and wherein motive means mounted on the support plate means moves the second bundle of rods and blocks and second rod shaping means together and wherein the bundles of rods are secured together by the clamping means when each of the first surfaces are defined by the first ends of the rods.

22. The method for producing a cross-sectionally shaped beam of radiation from a radiation source which comprises:

(a) providing a collimator apparatus for producing a cross-sectionally shaped beam of radiation from a radiation source which comprises: support plate means having a central opening around a beam axis through which the beam of radiation can pass; a bundle of nested rods mounted adjacent the support plate means each rod being movable into the beam at an angle to the beam axis to interfere with the beam, the rods having first ends which together define a first surface for shaping the beam around the beam axis and opposite second ends from the first ends of the rods; a holder means including spaced apart blocks mounted adjacent the support plate, each block having axially aligned holes mounting the rods so that the first surface is defined and the beam is shaped by the first ends of the rods; releasable clamping means for moving the blocks so that the blocks or means between the blocks adjacent the rods are in engagement with the rods to secure the rods together in the shape defined by the first ends of the rods;

(b) moving the rods in the holes in the block so that the rods define the first surface;

(c) clamping the rods with the releasable clamping means by moving the blocks to prevent movement of the rods; and

(d) producing the shaped beam defined by the first ends of the rods.

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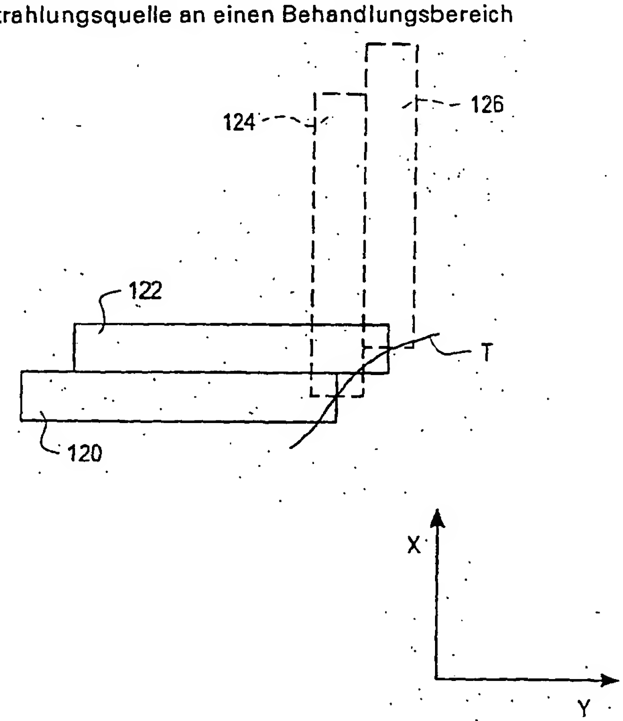
Die folgenden Angaben sind den vom Anmelder eingereichten Unterlagen entnommen

(54) Ein Verfahren zum Liefern von Strahlung von einer Strahlungsquelle an einen Behandlungsbereich

(57) Es wird ein Verfahren zum Liefern von Strahlung von einer Strahlungsquelle an einen Behandlungsbereich (T) unter Verwendung eines Mehrblattkollimators angegeben. Das Verfahren enthält das Positionieren des Mehrblattkollimators zwischen der Strahlungsquelle und dem Objekt zum Blockieren eines Teils der Strahlung. Die Blätter (120, 122) des Mehrblattkollimators sind im wesentlichen innerhalb einer Ebene befindlich und erstrecken sich entlang einer ersten Achse (Y). Die Blätter werden zum Definieren eines ersten Behandlungsfeldes positioniert. Das Verfahren enthält weiter das Liefern der Strahlung an das erste Behandlungsfeld und das Drehen des Mehrblattkollimators um eine zentrale Achse, die sich im wesentlichen senkrecht der Blattebene erstreckt. Die Blätter (124, 126) werden zum Definieren eines zweiten Behandlungsfeldes positioniert, und Strahlung wird an das zweite Behandlungsfeld geliefert.



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Beschreibung

[0001] Die vorliegende Erfindung bezieht sich auf ein Verfahren zum Liefern von Strahlung von einer Strahlungsquelle an einen Behandlungsbereich, insbesondere zur Verwendung bei einer hochdefinierten Strahlungsbehandlung mit einem intensitätsmodulierenden Mehrblattkollimator.

[0002] Strahlungsemissionsvorrichtungen sind allgemein bekannt und werden zum Beispiel als Bestrahlungstherapievorrichtungen für die Behandlung von Patienten verwendet. Eine Bestrahlungstherapievorrichtung enthält allgemein ein Gerüst oder Gestell (zum Beispiel ein Portal, Gantry), das um eine horizontale Drehachse im Verlauf einer therapeutischen Behandlung geschwenkt werden kann. Ein Linearbeschleuniger ist innerhalb des Gestells zum Erzeugen eines Hochenergie-Bestrahlungsstrahls für die Therapie befindlich. Dieser Hochenergie-Bestrahlungsstrahl kann zum Beispiel ein Elektronenstrahl oder ein Photonenstrahl (Röntgenstrahl) sein. Während der Behandlung wird der Bestrahlungsstrahl auf eine Zone eines Patienten, der in dem Isozentrum der Gestelldrehung liegt, gerichtet bzw. kanalisiert.

[0003] Um die Strahlung, die in Richtung des Patienten emittiert wird, zu steuern, ist typischerweise eine Strahlungsabschirmvorrichtung wie eine Plattenanordnung oder ein Kollimator in der Trajektorie des Strahlungsstrahls zwischen der Strahlungsquelle und dem Patienten vorgesehen. Ein Beispiel einer Plattenanordnung ist ein Satz von vier Platten, der zum Definieren einer Öffnung für den Strahlungsstrahl benutzt werden kann. Der Kollimator ist eine Strahlabschirmungsvorrichtung, die mehrere Blätter (z. B. relativ dünne Platten oder Stäbe) enthalten kann, die typischerweise als gegenüberliegende Blattpaare angeordnet sind. Die Platten sind aus einem relativ dichten und strahlungsundurchlässigen Material ausgebildet und sie sind im allgemeinen unabhängig voneinander zum Begrenzen des Strahlungsstrahles positionierbar.

[0004] Die Strahlabschirmungsvorrichtung definiert ein Feld auf der Zone des Patienten, für welches eine vorgeschriebene Strahlungsmenge zu liefern ist. Die gewöhnliche Behandlungsfeldgestalt resultiert in einem dreidimensionalen Behandlungsvolumen, das Segmente von normalem Gewebe enthält, wodurch die Dosis, die dem Tumor gegeben werden kann, begrenzt wird. Die an den Tumor gelieferte Dosis kann erhöht werden, falls die Menge normalen Gewebes, die bestrahlt wird, vermindert wird und die an das normale Gewebe gelieferte Dosis vermindert wird. Die Vermeidung des Lieferns von Strahlung an gesunde Organe, die den Tumor umgeben und überlagern, begrenzt die Dosis, die an den Tumor geliefert werden kann.

[0005] Die Lieferung von Strahlung durch eine Bestrahlungstherapievorrichtung wird typischerweise durch einen Onkologen vorgeschrieben. Die Verschreibung ist eine Definition eines bestimmten Volumens und eines bestimmten Bestrahlungspegels, von dem gestattet ist, daß er an dieses Volumen geliefert wird. Der tatsächliche Betrieb der Bestrahlungsausrüstung wird jedoch normalerweise durch einen Therapeuten ausgeführt. Die Bestrahlungsemissionsvorrichtung wird zum Liefern der spezifischen Behandlung, die durch den Onkologen vorgeschrieben worden ist, programmiert. Wenn die Vorrichtung zur Behandlung programmiert wird, hat der Therapeut die tatsächliche Strahlungsausgabe in Betracht zu ziehen und die Dosislieferung basierend auf der Plattenanordnungsöffnung einzustellen, um die vorgeschriebene Strahlungsbehandlung in der gewünschten Tiefe in dem Ziel zu erreichen.

[0006] Die Herausforderung für den Bestrahlungstherapeuten ist die Bestimmung der besten Anzahl von Feldern und Intensitätspegeln zum Optimieren der Dosis-Volumen-Histogramme, die einen kumulativen Pegel der Strahlung definieren, der an ein spezifiziertes Volumen zu liefern ist. Typische Optimierungsmaschinen optimieren die Dosis-Volumen-Histogramme durch Berücksichtigung der Verschreibung des Onkologen oder einer dreidimensionalen Spezifizierung der zu liefernden Dosis bzw. Dosierung. Bei solchen Optimierungsmaschinen wird das dreidimensionale Volumen in Zellen heruntergebrochen, wobei jede Zelle einen spezifischen Strahlungspegel, der zu handhaben ist, definiert. Die Ausgaben der Optimierungsmaschinen sind Intensitätskarten, die durch Variieren der Intensität in jeder Zelle in der Karte bestimmt sind. Die Intensitätskarten spezifizieren eine Anzahl von Feldern, die optimierte Intensitätspegel in jeder Zelle definieren. Die Felder können statisch oder dynamisch moduliert werden, so daß eine unterschiedliche akkumulierte der Dosierung bzw. Dosis an unterschiedlichen Punkten in dem Feld empfangen wird. Wenn die Strahlung einmal entsprechend der Intensitätskarte geliefert worden ist, sollte die akkumulierte Dosis bzw. Dosierung in jeder Zelle, oder das Dosis-Volumen-Histogramm, der Verschreibung so nahe wie möglich entsprechen.

[0007] Verfahren, mit denen das Behandlungsvolumen dazu gebracht werden kann, einem Tumor genauer zu entsprechen, enthalten das Definieren der Tumorgestalt mit einem Bleilegierungsblock, das Bewegen von festen Klauenblöcken während der Behandlung, das Abtasten mit dem Strahlungsstrahl über das zu behandelnde Volumen, und das Verwenden eines Mehrblattkollimators, um ein unregelmäßig geformtes Feld zu erzeugen, das im wesentlichen der Gestalt des Tumors entspricht. Der Mehrblattkollimator enthält zwei gegenüberliegende Felder von Seite-an-Seite angeordneten, länglichen, strahlungsblockierenden Kollimatorblättern. Jedes Blatt kann longitudinal in Richtung auf die oder weg von der zentralen Achse des Strahls bewegt werden, wodurch eine gewünschte Gestalt definiert wird, durch welche der Strahlungsstrahl hindurchgehen wird. Mehrblattkollimatoren werden in zunehmendem Maße verwendet, um Bleilegierungsblöcke bei vielen konformen (formtreuen) Strahlungsbehandlungen zu ersetzen, um Kosten und die zur Erzeugung des Blockes benötigte Zeit zu reduzieren. Jedoch gibt es immer noch eine Anzahl von Behandlungsfällen, die die Verwendung von Blöcken erfordern, da das konforme (formtreue) Formen unter Verwendung eines Mehrblattkollimators in diesen Fällen nicht adäquat verwirklicht werden kann. Dieses ist aufgrund des "Treppenstufen"-Effektes, der entlang der Feldränder auftritt, die nicht senkrecht zu den Blattflächenrändern sind. Ein welliges Strahlungsmuster an der Grenze eines bestrahlten Volumens ergibt sich, wenn die Blätter zum Erzeugen einer unregelmäßigen Gestalt gestuft sind. Diese Verteilung ist nicht akzeptabel für Feldränder, die benachbart zu kritischen Strukturen sind, oder wenn ein Aneinanderstoßen mit zusätzlichen Feldern geplant ist.

[0008] Ein Verfahren zum Reduzieren dieses Treppenstufeneffektes ist das Unterteilen der Behandlungsdosis in mehrere Intensitätsfelder und das Verschieben des Tisches, auf dem der Patient liegt, zwischen den Lieferungen (Anwendungen) jedes Intensitätsfeldes, d. h. der jeweiligen Intensitätsfelder. Jedoch ist dieses oft nicht wünschenswert, da die Tischverschiebungen das geplante Isozentrum bewegen.

[0009] Eine andere mögliche Lösung ist das Vorsehen eines Kollimators mit dünneren Blättern. Jedoch ist die für die zusätzlichen Blätter benötigte Hardware teuer, fügt dem System Gewicht hinzu, kann den Freiraum zwischen dem Behandlungskopf und dem Patienten reduzieren, und kann die Zuverlässigkeit und die Lebensdauer des Systems vermindern.

[0010] Dementsprechend gibt es ein Bedürfnis nach einem Verfahren zum Erzielen einer Intensitätsmodulation mit

einer höheren räumlichen Auflösung, um Treppenstufeneffekte an kritischen Grenzen während einer Bestrahlungstherapie zu vermindern, ohne die momentanen Mehrblattkollimatorblattbreiten zu ändern oder den Patienten während der Bestrahlungsbehandlung zu verschieben.

[0011] Dieses Bedürfnis wird befriedigt durch ein Verfahren nach Anspruch 1.

[0012] Weiterbildungen sind in den Unteransprüchen angegeben.

[0013] Bei einer Ausführungsform wird der Kollimator gedreht, bis sich die Blätter longitudinal entlang einer zweiten Achse, die im wesentlichen senkrecht zu der ersten Achse ist, erstrecken. Die Blätter können longitudinal zum Erzeugen zusätzlicher Behandlungsfelder bewegt werden. Eine vorgeschriebene Strahlungsdosis wird bevorzugterweise gleichmäßig unter den unterschiedlichen Behandlungsfeldern aufgeteilt.

[0014] Das Verfahren kann weiter das Unterteilen des Behandlungsbereichs in eine Mehrzahl von Zellen enthalten, von denen jede einen definierten Behandlungsintensitätspegel aufweist. Die Zellen werden zur Bildung einer Mehrzahl von Matrizen gruppiert, wobei jede der Matrizen mindestens eine Abmessung aufweist, die ungefähr gleich der Breite eines Kollimatorblattes ist. Jede der Matrizen wird zerlegt in orthogonale Matrizen für eine Bestrahlung mit einem Null-Grad-Offset-Kollimator und einem Neunzig-Grad-Offset-Kollimator.

[0015] Das Obige ist eine kurze Beschreibung von einigen Nachteilen des Standes der Technik und Vorteilen der vorliegenden Erfindung. Andere Merkmale und Vorteile ergeben sich aus der folgenden Beschreibung von Ausführungsbeispielen unter Bezugnahme auf die Figuren. Von den Figuren zeigen:

[0016] **Fig.** 1 eine Darstellung einer Bestrahlungsbehandlungsvorrichtung und einer Behandlungskonsole entsprechend einer Ausführungsform der vorliegenden Erfindung und einen Patienten, der zur Behandlung innerhalb der Bestrahlungsvorrichtung positioniert ist;

[0017] **Fig.** 2 eine Blockdarstellung, die Teile der Bestrahlungsbehandlungsvorrichtung aus **Fig.** 1 illustriert;

[0018] **Fig.** 3 ein Schema, das Blätter des Mehrblattkollimators, die zur Behandlung in der Strahlungsbehandlungsvorrichtung aus **Fig.** 1 positioniert sind, illustriert;

[0019] **Fig.** 4 eine Draufsicht, die einen Teil der Blätter des Mehrblattkollimators, die in einer ersten Position positioniert sind, und Blätter, die gestrichelt gezeigt sind, des in einer zweiten Position positionierten Kollimators, illustriert;

[0020] **Fig.** 5 eine Draufsicht des Mehrblattkollimators, der in einer Null-Grad-Offset-Position positioniert ist;

[0021] **Fig.** 6 eine Draufsicht des Mehrblattkollimators aus **Fig.** 5, der in einer Neunzig-Grad-Offset-Position positioniert ist;

[0022] **Fig.** 7 eine Draufsicht von zwei Blättern, die eine Grenze eines Behandlungsbereichs schneiden, wobei die Blätter in einer zweiten Position gestrichelt gezeigt sind;

[0023] **Fig.** 8 eine Draufsicht auf zwei Blätter, die die Grenze des Behandlungsbereichs schneiden, wobei der Kollimator aus seiner Null-Grad-Offset-Position gedreht ist, und wobei die Blätter in einer zweiten Position gestrichelt gezeigt sind;

[0024] **Fig.** 9 eine Draufsicht auf einen Behandlungsbereich, der in zwei Abschnitte für eine Strahlungslieferung mit dem in seiner Null-Grad-Offset-Orientierung positionierten Kollimator unterteilt ist;

[0025] **Fig.** 10 eine Draufsicht des Behandlungsbereichs aus **Fig.** 9, der in zwei Abschnitte für eine Strahlungslieferung mit dem in seiner Neunzig-Grad-Offset-Orientierung positionierten Kollimator unterteilt ist;

[0026] **Fig.** 11 eine Draufsicht eines Behandlungsbereichs mit einem Gitter, das über dem Behandlungsbereich zum Definieren von Zellen innerhalb des Behandlungsbereiches plaziert ist;

[0027] **Fig.** 12 ein Schema, das die Zellen aus **Fig.** 11, die in einer Intensitätskarte befindlich sind, illustriert;

[0028] **Fig.** 13 eine Darstellung einer Matrix, die in eine Null-Grad-Matrix-Komponente und eine Neunzig-Grad-Matrix-Komponente heruntergebrochen ist;

[0029] **Fig.** 14 eine Draufsicht auf ein gegenüberliegendes Paar von Blättern, die zum Anwenden einer Dosierung, die durch die Null-Grad-Matrix aus **Fig.** 13 spezifiziert ist, konfiguriert sind;

[0030] **Fig.** 15 eine Draufsicht auf ein gegenüberliegendes Paar von Blättern, die zum Anwenden einer Dosierung, die durch die Neunzig-Grad-Matrix aus **Fig.** 13 spezifiziert ist, konfiguriert sind; und

[0031] **Fig.** 16 eine Ablaufdarstellung, die einen Prozess zum Definieren einer Intensitätskarte für einen Behandlungsbereich und zum Liefern von Strahlung an den Behandlungsbereich illustriert.

[0032] Dieselben Bezugszeichen bezeichnen entsprechende Teile durch die Figuren.

[0033] Die folgende Beschreibung wird gegeben, um Durchschnittsfachleute in die Lage zu versetzen, die Erfindung auszuführen, und sie wird im Kontext von Patentanmeldungen und ihren Anforderungen gegeben. Verschiedene Modifikationen der bevorzugten Ausführungsformen werden den Fachleuten leicht einfallen und die grundsätzlichen Prinzipien, die hier beschrieben werden, können auf alle Ausführungsformen angewandt werden.

[0034] Unter Bezugnahme auf die Figuren, und zuerst unter Bezugnahme auf **Fig.** 1, eine Strahlungsbehandlungsvorrichtung nach einer Ausführungsform der vorliegenden Erfindung ist in **Fig.** 1 gezeigt und allgemein mit dem Bezugszeichen **20** bezeichnet. Die Strahlungsbehandlungsvorrichtung **20** weist eine Strahlabschirmungsvorrichtung (nicht gezeigt) innerhalb eines Behandlungskopfes **24**, eine Steuereinheit innerhalb eines Gehäuses **26**, das mit einer Behandlungsverarbeitungseinheit, die allgemein mit **30** bezeichnet ist, verbunden ist, auf. Die Strahlungsbehandlungsvorrichtung weist weiter ein Gestell (Gerüst, Portal, Gantry) **36**, das zur Drehung um die Achse A im Laufe einer therapeutischen Behandlung geschwenkt bzw. gedreht werden kann, auf. Der Behandlungskopf **24** ist an dem Gestell **36** zur Bewegung mit diesem befestigt. Ein Linearbeschleuniger ist innerhalb des Gestells zur Erzeugung einer Hochleistungsstrahlung, die zur Therapie verwendet wird, befindlich. Die Strahlung, die von dem Linearbeschleuniger emittiert wird, verläuft allgemein entlang der Achse R. Elektronen, Photonen, oder irgendeine andere detektierbare Strahlung kann für die Therapie verwendet werden. Während der Behandlung wird der Strahlungsstrahl auf eine Zone Z eines Objektes P (z. B. ein Patient, der zu behandeln ist) fokussiert. Die zu behandelnde Zone ist in einem Isozentrum befindlich, das durch den Schnitt der Drehachse A des Gestells **36**, der Drehachse T des Behandlungstisches **38**, und der Strahlungsstrahlachse R definiert wird. Das drehbare Gestell **36** erlaubt unterschiedliche Strahlwinkel und Bestrahlungsverteilungen, ohne daß der Patient bewegt werden muß.

[0035] Die Behandlungsverarbeitungseinheit **30** wird zum Eingeben von Information, wie der Bestrahlungsintensität und dem Ort der Behandlung, in die Strahlungsbehandlungsvorrichtung **20** und zum Ausgeben von Daten zum Überwachen der Behandlung verwendet. Die Verarbeitungseinheit **30** enthält eine Ausgabevorrichtung, wie einen visuellen Anzeigemonitor **40** und eine Eingabevorrichtung wie eine Tastatur **42**. Die Behandlungsverarbeitungseinheit **30**

wird typischerweise durch einen Therapeuten betätigt, der die tatsächliche Lieferung der Bestrahlungsbehandlung, wie sie durch einen Onkologen vorgeschrieben worden ist, verwaltet bzw. überwacht. Der Therapeut verwendet die Tastatur **42** zum Eingeben von Daten, die die Bestrahlungsdosis, die an den Patienten zu liefern ist, definieren, in die Verarbeitungseinheit **30**. Die Daten können auch über andere Eingabevorrichtungen wie zum Beispiel eine Datenspeichervorrichtung eingegeben werden. Verschiedene Datentypen können vor und während der Behandlung auf dem Schirm des Anzeigemonitors **40** angezeigt werden.

[0036] **Fig.** 2 ist eine Blockdarstellung der Bestrahlungsbehandlungsvorrichtung, die Abschnitte der Behandlungsverarbeitungseinheit **30** in weiterem Detail zeigt. Ein Elektronenstrahl **50** wird in einem Elektronenbeschleuniger, der allgemein mit **52** bezeichnet ist, erzeugt. Der Elektronenbeschleuniger **52** enthält eine Elektronenkanone **54**, einen Wellenleiter **56** und eine evakuierte Umhüllung oder einen evakuierten Führungsmagneten **58**. Ein Triggersystem **60** erzeugt Injektortriggersignale und liefert sie an einen Injektor **62**. Basierend auf diesen Injektortriggersignalen erzeugt der Injektor **62** Injektorpulse, die an die Elektronenkanone **54** in den Beschleuniger **52** zum Erzeugen des Elektronenstrahls **50** geliefert werden. Der Elektronenstrahl **50** wird durch den Wellenleiter **56** beschleunigt und geführt. Zu diesem Zweck ist eine Hochfrequenzquelle (nicht gezeigt) vorgesehen, die Hochfrequenzsignale für die Erzeugung eines elektromagnetischen Feldes liefert, das an den Wellenleiter **56** geliefert wird. Die Elektronen, die durch den Injektor **62** injiziert und durch die Elektronenkanone **54** emittiert werden, werden durch das elektromagnetische Feld in dem Wellenleiter **56** beschleunigt und treten an dem Ende, das der Elektronenkanone **54** entgegengesetzt ist, zur Bildung des Elektronenstrahls **50** aus. Der Elektronenstrahl **50** tritt dann in den Führungsmagneten **58** ein und wird von dort durch ein Fenster **64** entlang der Achse R geführt. Nach dem Durchgang durch eine Streufolie **66** für den Elektronenmodus (oder ein Target für den Photonenmodus) tritt der Strahl **50** durch einen Durchgang **68** eines Abschirmungsblockes **70** und trifft auf eine Sekundärstreufolie **72** für den Elektronenmodus (oder ein Glättungsfilter für den Photonenmodus).

[0037] Der Strahl tritt als nächstes durch eine Meßkammer **74**, in der die Dosis festgestellt wird. Eine Strahlabschirmungsvorrichtung, allgemein mit **80** bezeichnet, ist in dem Weg des Strahls **50** vorgesehen, um ein Behandlungsfeld **81** (**Fig.** 2 und 3) zu definieren. Die Strahlabschirmungsvorrichtung **80** enthält eine Mehrzahl von gegenüberliegenden Platten oder Blättern **82a–i** und **84a–i**, von denen in **Fig.** 2 zur Vereinfachung nur zwei gezeigt sind. **Fig.** 3 illustriert die Blätter **82a** i und **84a** i (die Blattpaare **82a** und **84a**, **82b** und **84b**, . . ., **82i** und **84i** bilden) eines Mehrblattkollimators, der zwischen der Strahlungsquelle und einem Patienten montiert und zum Definieren eines Behandlungsfeldes durch Begrenzen des Elektronenstrahls **50** positioniert ist. Die Blätter **82a–i**, **84a–i** haben typischerweise eine Breite von einem Zentimeter und sind im wesentlichen undurchlässig für die emittierte Strahlung, so daß sie gesundes Gewebe gegenüber der Strahlung abblocken bzw. abschirmen.

[0038] Die Blätter **82a–i**, **84a–i** sind in einer Richtung, die allgemein bzw. im wesentlichen senkrecht zu der Achse R ist, durch eine Antriebseinheit **86** (die in **Fig.** 2 nur in bezug auf die Platte **82a** gezeigt ist) zum Ändern der Größe des bestrahlten Feldes bewegbar, so daß die Strahlungsverteilung über das Feld nicht gleichförmig sein muß (d. h., ein Bereich kann einer höheren Dosis als ein anderer Bereich ausgesetzt werden). Die Antriebseinheit **86** enthält einen elektrischen Motor, der mit der Platte **82a** gekoppelt ist und durch eine Motorsteuerung **90** gesteuert wird. Positionssensoren **92**, **94** sind ebenfalls mit den Platten **82a** bzw. **84a** zum Erfassen ihrer Positionen gekoppelt. Die Antriebseinheit **86** treibt die Platte **82a** zur Bewegung in das und aus dem Behandlungsfeld an, wodurch die gewünschten Feldgestalten erzeugt werden.

[0039] Die Motorsteuerung **90** ist mit einer Dosissteuereinheit **96** gekoppelt, die eine Dosimetriesteuerung enthält, die mit der zentralen Prozessoreinheit **28** zum Liefern von Einstellwerten für den Strahlungsstrahl zum Erzielen gegebener Isodosiskurven gekoppelt ist (**Fig.** 2). Die Ausgabe des Strahlungsstrahls (d. h. dessen Energie/Leistung) wird durch die Meßkammer **74** gemessen. Als Reaktion auf eine Abweichung zwischen dem eingestellten Wert und den tatsächlichen Werten liefert die Dosissteuereinheit **96** Signale an das Triggersystem **60**, das in einer bekannten Weise die Pulswiederholfrequenz so ändert, daß die Abweichung zwischen den eingestellten Werten und den tatsächlichen Werten der Strahlungsstrahlausgabe (Energie/Leistung) minimiert wird. Die durch den Patienten absorbierte Dosis ist abhängig von der Bewegung der Kollimatorplatten **82a**, **84a**. Die zentrale Prozessoreinheit **28** steuert das Ausführen des Programms und das Öffnen und Schließen der Kollimatorplatten **82a**, **84a** zum Liefern einer Strahlung entsprechend eines gewünschten Intensitätsprofils. Die zentrale Prozessoreinheit **28** kann andere Merkmale enthalten, wie sie zum Beispiel in der US 5 724 403 beschrieben sind, die hier zu diesem Zweck in ihrer Gesamtheit durch Bezugnahme aufgenommen wird.

[0040] Es ist zu verstehen, daß die Strahlungsbehandlungsvorrichtung unterschiedlich von derjenigen sein kann, die hier beschrieben und gezeigt wurde. Die oben beschriebene Behandlungsvorrichtung **20** ist ein Beispiel einer Vorrichtung zur Verwendung beim Liefern einer Behandlung entsprechend des Verfahrens, das unten beschrieben wird.

[0041] Im Folgenden werden Verfahren nach Ausführungsformen der vorliegenden Erfindung zum Liefern von Strahlung an einen Behandlungsbereich mit einem Mehrblattkollimator, der zum Drehen um eine Achse R des Strahlungsstrahls ansteuerbar ist, die mit einer zentralen Achse übereinstimmt, die sich im wesentlichen senkrecht zu einer Ebene erstreckt, die mindestens einen Teil der Blätter des Mehrblattkollimators enthält (**Fig.** 1), beschrieben. Die Verfahren enthalten das Anwenden einer ersten Strahlungsbehandlung auf einen Behandlungsbereich mit dem Kollimator in einer ersten Position und dann das Drehen des Kollimators um die Achse R und das Anwenden einer zweiten Strahlungsbehandlung. Um den Treppenstufeneffekt, der durch die Breite der Blätter erzeugt wird, zu reduzieren, wird die Strahlung in zwei oder mehr getrennten Behandlungsfeldern geliefert, wobei das erste Behandlungsfeld ein Behandlungsfeld ist, bei dem der Kollimator in einer Null-Grad-Offset-Orientierung ist, und das zweite Behandlungsfeld ein Behandlungsfeld ist, bei dem der Kollimator um ungefähr neunzig Grad gegenüber der ersten Kollimatorposition versetzt bzw. verdreht ist. Die Null-Grad-Offset-Orientierung des Kollimators kann entsprechend Prozeduren ausgewählt werden, die zum Auswählen der optimalen Kollimatororientierung für eine herkömmliche Mehrblattkollimatorstrahlungslieferung (d. h. keine Kollimatordrehung um die Achse R) verwendet werden. Softwareprodukte wie "Beamshaper" können zum Bestimmen der optimalen Kollimatororientierung verwendet werden, wie es den Durchschnittsfachleuten wohlbekannt ist. Wie unten beschrieben wird, wird der Kollimator bevorzugterweise um ungefähr neunzig Grad relativ zu der Null-Grad-Position gedreht, jedoch können die beiden Kollimatorpositionen auch um eine

Winkeldrehung unterschiedlich von neunzig Grad voneinander getrennt sein, oder die Strahlung kann mit einem Kollimator, der in mehr als zwei Winkelorientierungen positioniert ist, ausgestrahlt werden, ohne daß von der Erfindung abgewichen wird.

[0042] Das erste Verfahren, das unten beschrieben wird, enthält das Positionieren der Blätter derart, daß ein vorderer Rand von jedem Blatt eine Grenze des Behandlungsbereiches an dem spezifizierten Ort schneidet. Das zweite Verfahren enthält das Definieren einer Intensitätskarte auf dem Behandlungsbereich und das Positionieren der Blätter basierend auf der Intensitätskarte. Das zweite Verfahren wird bevorzugt, falls die Grenze des Behandlungsbereiches steile (große Steigerung) Abschnitte, kurze Abschnitte oder scharfe Änderungen in der Krümmung aufweist.

[0043] Fig. 4 zeigt eine Teildraufsicht eines Behandlungsbereiches T und einen Teil der Blätter des Mehrblattkollimators, der in zwei unterschiedlichen Orientierungen positioniert ist, zum Definieren einer Grenze des Behandlungsbereichs. Die Blätter **120** und **122** erstrecken sich longitudinal entlang der Y-Achse, wobei der Kollimator in seiner Null-Grad-Offset-Orientierung positioniert ist (**Fig.** 4 und 5). Die Blätter **124** und **126** (in **Fig.** 4 gestrichelt gezeigt) erstrecken sich longitudinal entlang der X-Achse, wenn der Kollimator in seiner Neunzig-Grad-Offset-Position positioniert ist (**Fig.** 4 und 6). **Fig.** 4 illustriert, daß die Auflösung an der Grenze des Zielbereiches durch Anlegen der Strahlung in zwei unterschiedlichen Kollimatororientierungen erhöht werden kann. Die Blätter können außerdem longitudinal bewegt werden, während der Kollimator in derselben Orientierung bleibt, um die Auflösung weiter zu erhöhen. Wie in **Fig.** 7 und 8 gezeigt ist, die Blätter **120**, **122** und **124**, **126** schneiden einen Umfangsrand (Grenze) des Behandlungsbereichs T, wobei der Kollimator in seiner Null-Grad-Offset-Orientierung bzw. seiner Neunzig-Grad-Offset-Orientierung positioniert ist. Die Blätter, die gestrichelt gezeigt sind, sind longitudinal gegenüber einer ersten Position versetzt, um ein neues Behandlungsfeld zu erzeugen. Die Anzahl der Blattpositionen und der Kollimatororientierungen, die zur Reduzierung des Treppenstufeneffektes benötigt werden, hängt davon ab, wie fein oder "sanft" die Kontur gewünscht wird. Jedwede Anzahl von Intensitätsfeldern kann zum Liefern der Strahlung bei unterschiedlichen Kollimatororientierungen und verschiedenen longitudinalen Blattpositionen verwendet werden, um die gewünschte Kontur entlang des Umfangsrands des Behandlungsbereichs T zu liefern.

[0044] Bei dem ersten Verfahren zum Definieren von Blattpositionen für die unterschiedlichen Behandlungsfelder basiert die Position jedes Blattes relativ zu dem Umfangsrand des Behandlungsbereichs T auf der Anzahl der zu liefernden Behandlungsfelder. Falls nur zwei Behandlungsfelder geliefert werden, wird jedes Blatt derart positioniert, daß der Querrand (d. h. die vordere Fläche) **130** jedes Blattes die Grenze des Behandlungsbereichs ungefähr an ihrem Mittelpunkt (d. h. eine Hälfte der Blattbreite) schneidet (**Fig.** 5 und 6). Derart wird der Kollimator zuerst in seiner Null-Grad-Offset-Orientierung positioniert, wobei jedes Blatt zum Schneiden der Behandlungsbereichsgrenze an seinem Mittelpunkt positioniert ist, wie es in **Fig.** 5 gezeigt ist. Die Hälfte der Strahlungsdosis wird mit den Blättern, die dieses erste Behandlungsfeld definieren, geliefert. Der Kollimator wird dann um die zentrale Achse R gedreht, bis sich die Blätter im wesentlichen senkrecht zu ihrer ursprünglichen Blattposition erstrecken (**Fig.** 6). Die Blätter werden jeweils longitudinal entlang der X-Achse bewegt, bis jedes Blatt die Grenze ungefähr an dem Mittelpunkt der Blattkante **130** schneidet. Die verbleibende Hälfte der Strahlungsdosierung (Strahlungsdosis) wird dann mit den Blättern, die zum Definieren dieses zweiten Behandlungsfeldes positioniert sind, geliefert.

[0045] Falls drei separate Behandlungsfelder verwendet werden, kann ein Feld mit dem Mehrblattkollimator in einer ersten Orientierung geliefert werden, und die anderen beiden Felder können mit dem Mehrblattkollimator in einer zweiten Orientierung geliefert werden. Zum Beispiel kann das erste Behandlungsfeld geliefert werden, wie es oben für den Fall mit zwei Behandlungsfeldern beschrieben und in **Fig.** 5 gezeigt wurde. Der Kollimator wird dann zu seiner zweiten Orientierung (z. B. um neunzig Grad gegenüber der ersten Kollimatororientierung gedreht) gedreht und die Strahlung wird über zwei separate Behandlungsfelder geliefert, wobei die Blätter zwei unterschiedliche Punkte entlang der Grenze schneiden, wie es in **Fig.** 8 gezeigt und unten beschrieben ist.

[0046] Falls vier unterschiedliche Behandlungsfelder verwendet werden, wird die vorgeschriebene Anzahl von Überwachungseinheiten der Strahlung in vier gleiche Dosen unterteilt, wobei ein Viertel der Strahlung an jedes Behandlungsfeld geliefert wird. Die **Fig.** 7 und 8 zeigen Blätter, die für zwei Behandlungsfelder mit dem Kollimator in seiner Null-Grad-Offset-Position bzw. zwei Behandlungsfelder mit dem Kollimator in seiner Neunzig-Grad-Offset-Position positioniert sind. Die Strahlung wird zuerst mit den Blättern **120**, **122**, die zum Schneiden der Behandlungsbereichsgrenze an einem Ort, der ungefähr ein Drittel des Weges entlang der Querkante **130** jedes Blattes ist, positioniert (**Fig.** 7). Die Blätter **120**, **122** werden dann longitudinal bewegt (wie es gestrichelt gezeigt ist), bis jedes Blatt die Grenze an einem Ort schneidet, der ungefähr zwei Drittel des Weges entlang der Querkante des Blattes liegt.

[0047] Die folgende Gleichung kann zum Bestimmen der Anzahl von Blattpositionen benutzt werden, die für jede Kollimatororientierung mit einer gegebenen Anzahl von Behandlungsfeldern benötigt werden:

$m = n/2$ (für eine gerade Anzahl von Feldern)

wobei n = Anzahl der Behandlungsfelder und m = Anzahl der Blattpositionen für jede Kollimatororientierung.

[0048] Die Anzahl der vorgeschriebenen Überwachungseinheiten der Strahlung, die an jedes Feld geliefert werden, wird $1/n$ sein. Der Schnittpunkt der Blätter und der Grenze für jede Position wird in Intervallen von $1/(m+1)$-mal der Blattbreite sein. Falls zum Beispiel ein 1 cm breites Blatt verwendet wird und die Strahlung über sechs Behandlungsfelder zu liefern ist, wird die Anzahl der Blattpositionen für jede Kollimatororientierung (z. B. Null-Grad-Offset und Neunzig-Grad-Offset) sein:

$m = 6/2 = 3$

und der Schnittpunkt zwischen jedem Blatt und der Grenze wird in Intervallen von

$1/(3+1) = 1/4 \times 1$ cm

sein. Derart sind die Schnittpunkte bei 1/4 cm, 1/2 cm und 3/4 cm der Gesamtblattbreite entlang der Querkante **130** des Blattes.

[0049] Falls die Anzahl der Intensitätsfelder ungerade ist (d. h., $n = 2m+1$), liegen die Punkte entlang des Blattes in Intervallen von $1/(m+1)$-mal der Blattbreite in einer Kollimatororientierung und $1/(m+2)$-mal der Blattbreite in der anderen Kollimatororientierung. Die Kollimatororientierung, in der die größere Anzahl von Feldern geliefert wird, ist bevorzugterweise die Neunzig-Grad-Offset-Orientie-

rung, falls die Null-Grad-Offset-Orientierung einen Kollimatorwinkel hat, der bereits zur Minimierung des Treppenstufeneffektes optimiert worden ist. In dem Fall, in dem die Null-Grad-Offset-Position nicht durch einen Optimierungsprozess ausgewählt wurde, wird die Kollimatororientierung, die am besten mit einer Einzelbehandlungsfeldanwendung übereinstimmt, bevorzugterweise als die Orientierung ausgewählt, die weniger Bestrahlungsanwendungen hat bzw. empfängt.

[0050] Falls ein Behandlungsbereich T konkave und konvexe Bereiche aufweist, ist es schwierig, die Blätter derart zu positionieren, daß jedes Blatt einen einzigen Schnittpunkt entlang der Grenze des Behandlungsbereiches hat. Der Behandlungsbereich T kann in zwei oder mehr getrennte Bereiche unterteilt werden, wie es durch die gestrichelten Linien gezeigt ist, die auf den Behandlungsbereichen in **Fig.** 9 und 10 gezeigt sind. Jeder Abschnitt des Behandlungsbereiches weist nun einen einzigen (einzigartigen) Zusatz von Schnittpunkten auf und jeder Abschnitt erhält dieselbe Anzahl von Überwachungseinheiten der Strahlung, wie sie für den Behandlungsbereich vorgeschrieben ist. Die Behandlungsfelder werden individuell für jeden Abschnitt des Behandlungsbereiches T erzeugt, wie es zuvor beschrieben wurde. Da die Trennungslinie auf der Kollimatororientierung basiert, wird der Behandlungsbereich T für jede Orientierung unterschiedlich unterteilt. Die Blätter, die zum Definieren der Teilungslinie verwendet werden, sind bevorzugterweise leicht gegenüber der Linie versetzt, um einen Spielraum benachbart zu der Linie zu belassen. Dieser wird zum Korrigieren von Unterdosierungen, die an der Teilungslinie auftreten können, verwendet. Wie in **Fig.** 9 und 10 gezeigt ist, die Trennungslinien sind senkrecht zu der Richtung der Blattbewegung positioniert bzw. angeordnet. Dieses erlaubt es den Blättern, entlang des Randes zur Minimierung einer Unterdosierung an der Teilungslinie aufgrund von Übereinstimmungslinienwirkungen (d. h. Verbindungswirkungen) positioniert zu werden. Falls die Teilungslinie anstatt dessen parallel zu der Blattbewegungsrichtung und entlang einer Blattseite positioniert ist, kann eine Unterdosierung auftreten. Die Unterdosierung kann nicht korrigiert werden, da die Blätter nicht senkrecht zu der Teilungslinie bewegt werden können. Die Blätter, die zum Definierung der Teilungslinie verwendet werden, sind bevorzugterweise leicht gegenüber der Linie versetzt, um einen Spielraum benachbart zu der Linie zu belassen. Dieses wird zum Korrigieren von Unterdosierungen verwendet, die an der Teilungslinie auftreten können.

[0051] Während das oben beschriebene Verfahren gut bei Behandlungsbereichen wirkt, die Grenzen mit relativ kleinen Steigungen und sanfte Übergänge zwischen Richtungsänderungen aufweisen, ist ein bevorzugtes Verfahren für Behandlungsbereiche, die unregelmäßige Grenzen aufweisen, das Plazieren eines Gitters über dem Behandlungsbereich und das Definieren einer Mehrzahl von Intensitätszellen innerhalb des Behandlungsbereichs, um die geeigneten Blattpositionen zu bestimmen. Wie in **Fig.** 11 gezeigt ist, ein Gitter **97** wird über dem Behandlungsbereich T derart plaziert, daß die Quadrate so positioniert sind, daß sie mit den Blättern der beiden orthogonalen Kollimatororientierungen ausgerichtet sind. Die Zellen des Gitters **97** weisen bevorzugterweise eine Seite mit einer Länge auf, die gleich eines Bruchteils (1/n, wobei n eine ganze Zahl ist) der Breite der Kollimatorblätter ist. Die andere Seite der Zelle kann einen größeren oder kleineren Wert als n in dem 1/n-Bruchteil der Blattbreite aufweisen, wie unten beschrieben wird. Zum Beispiel kann der Behandlungsbereich in 5 mm × 5 mm Zellen oder 2 mm × 5 mm Zellen zur Verwendung mit einem Mehrblattkollimator, der Blattbreiten von 1 cm aufweist, unterteilt werden. Andere Gittergrößen können mit Blättern unterschiedlicher Breite verwendet werden.

[0052] Alle Zellen, die innerhalb des Behandlungsbereichs T befindlich sind, empfangen die Hälfte der vorgeschriebenen Dosierung in jeder Kollimatororientierung. Diese Zellen werden identifiziert mit "1" in **Fig.** 11. Die Zellen, die vollständig außerhalb des Behandlungsbereichs **5** befindlich sind, empfangen gar keine Strahlung. Diese Zellen sind mit "0" in **Fig.** 11 identifiziert. Diejenigen Zellen, die auf der Grenze des Behandlungsbereichs T befindlich sind, empfangen entweder die volle Strahlung oder keine Strahlung, abhängig davon, wieviel der Zelle innerhalb des Behandlungsbereichs befindlich ist. Falls 50% oder mehr der Zelle innerhalb des Behandlungsbereichs befindlich ist, wird die Zelle die volle Strahlung erhalten, und falls weniger als 50% der Zelle innerhalb des Behandlungsbereichs befindlich sind, wird die gesamte Zelle keine Strahlung erhalten.

[0053] **Fig.** 12 zeigt eine Intensitätskarte, die eine Mehrzahl von 1 cm × 1 cm Makrozellen **100** (durch fette durchgezogene Linien angezeigt), die in vier 5 mm × 5 mm Mikrozellen **102** (durch gestrichelte Linien angezeigt) unterteilt sind, aufweist. Die 5 mm × 5 mm Mikrozellen **102** werden zum Umwandeln einer Makrozelle **100** in zwei orthogonale Intensitätskarten, eine mit einer Auflösung von 5 mm × 10 mm und die andere mit einer Auflösung von 10 mm × 5 mm, verwendet. Ein Beispiel eines Prozesses zum Unterteilen der Intensitätskarte in Gruppen von vier 5 mm × 5 mm Mikrozellen **102** ist in der U.S. Patentanmeldung mit der Seriennummer 09/234,364 von Siochi, die am 20. Januar 1999 eingereicht wurde, die hier durch Bezugnahme in dieser Hinsicht aufgenommen wird, beschrieben. Dieses Gruppieren von 5 mm × 5 mm Mikrozellen **102** erlaubt die Behandlung eines Feldes mit einer 5 mm × 5 mm Auflösung unter Verwendung eines Mehrblattkollimators, der Blätter mit 1 cm Breite aufweist, wie es in **Fig.** 3 gezeigt ist.

[0054] **Fig.** 13 illustriert ein Beispiel einer Matrix **104**, die aus einer Intensitätskarte ausgebildet ist, die aus 5 mm × 5 mm Mikrozellen **106**, **108**, **110**, **112** zusammengesetzt ist. Jede Mikrozelle **106**, **108**, **110**, **112** identifiziert einen Abschnitt in einem mit Strahlung zu behandelnden Feld. Die Zahlen (0, 1, 1, 2) innerhalb jeder Mikrozelle **106**, **108**, **110** bzw. **112** repräsentieren den Strahlungsintensitätspegel für Orte innerhalb des Feldes und sind in Überwachungseinheiten (Monitor Units = mu) oder in relativen Überwachungseinheitsintensitäten (z. B. 1×10^2 mu) angegeben. Um eine 5 mm × 5 mm Auflösung für die Intensitätskarte zu liefern, wird die Matrix **104** in zwei orthogonale Matrizen **116**, **118** heruntergebrochen, die eine 1 cm × 5 mm Auflösung bzw. eine 5 mm × 1 cm Auflösung aufweisen. Ein Mehrblattkollimator mit einem Zentimeter breiten Blättern kann dann zum Liefern der Intensitätskarte mit einer 5 mm × 5 mm Auflösung verwendet werden. Zum Beispiel kann ein Paar von Blättern **97**, **98**, das wie in **Fig.** 14 gezeigt positioniert wird, zum Liefern der Intensitätskarte verwendet werden, die in der Matrix **116** aus **Fig.** 13 gezeigt ist. Eine Strahlungsdosis (z. B. 1 mu) wird an Felder angelegt, die den Mikrozellen **108** und **112** der Matrix **104** entsprechen. Der Kollimator wird dann um ungefähr neunzig Grad gedreht, um die Intensitätskarte, die in der Matrix **118** gezeigt ist, mit den Blattpositionen, die in **Fig.** 15 gezeigt sind, zu liefern. Mit dem um neunzig Grad gedrehten Kollimator wird eine Strahlungsdosis (z. B. 1 mu) an die Felder angelegt, die den Mikrozellen **110** und **112** aus der Matrix **104** entsprechen. Die zwei Strahlungsanwendungen resultieren in einer Dosis von 2 mu in dem Feld, das der Mikrozelle **112** entspricht, in einer Dosis von 1 mu in den Feldern, die den

Mikrozellen **108** und **110** entsprechen, und darin, daß keine Strahlung an das Feld angelegt wird, das der Mikrozelle **106** entspricht. Die Zerlegung der Matrix **104** in orthogonale Matrizen **116** und **118** liefert derart eine Behandlung mit einer 5 mm × 5 mm Auflösung unter Verwendung von Kollimatorblättern, die eine Breite von einem Zentimeter aufweisen.

[0055] Die Intensitätskarte wird zerlegt zum Definieren von zwei orthogonalen Karten, einer Null-Grad-Karte zur Anwendung bei einer Null-Grad-Offset-Kollimatoreinstellung und eine Neunzig-Grad-Karte zur Anwendung mit einer dazu senkrechten Kollimatoreinstellung. In der folgenden Beschreibung wird die ursprünglich eingegebene Intensitätskarte als eine Makromatrix definiert und die Gruppen von vier Mikrozellen innerhalb der Makromatrix werden als Mikromatrizen (oder Matrizen) definiert. Damit die Intensitätskarte in orthogonale Karten zerlegt wird, müssen die senkrechten Gradienten jeder Spalte der Mikromatrix (Matrix) **100** einander gleich sein und die horizontalen Gradienten jeder Zeile der Mikromatrix müssen ebenfalls einander gleich sein (**Fig.** 12). Dieses liefert einen 1 cm × 1 cm Bereich unter dem Schnittpunkt eines Blattpaares für eine Kollimatoreinstellung und eines anderen Blattpaares für die orthogonale Kollimatoreinstellung. Falls zum Beispiel die horizontalen Gradienten für die Mikromatrix, die die Zellen **102** aufweist (in **Fig.** 12 gezeigt), gleich sind, muß die folgende Gleichung gelten:

$$b-a = d-c$$

wobei a, b c, d die Intensitätswerte sind, die den Orten in der Mikromatrix **102** aus **Fig.** 12 entsprechen.

[0056] In ähnlicher Weise muß, falls die vertikalen Gradienten gleich sind, die folgende Gleichung gelten:

$$c-a = d-b.$$

[0057] Ein Verfahren zum Umwandeln einer Intensitätskarte, die die oben Randbedingungen nicht erfüllt (d. h., die horizontalen Gradienten für jede Zeile sind nicht gleich und/oder die vertikalen Gradienten für jede Spalte sind nicht gleich), in eine Intensitätskarte, die gleiche horizontale und vertikale Gradienten aufweist, ist in der U.S. Patentanmeldung mit der Seriennummer 09/457,601, die am 8. Dezember 1999 eingereicht wurde, die hier diesbezüglich durch Bezugnahme aufgenommen wird, beschrieben. Verschiedene Zerlegungen einer Intensitätskarte sind zum Erzeugen von zwei orthogonalen Karten möglich. Ein Optimierungsverfahren, wie es in der U.S. Patentanmeldung mit der Seriennummer 09/457,602, die am 8. Dezember 1999 eingereicht wurde, beschrieben ist, die hier diesbezüglich durch Bezugnahme aufgenommen wird, kann zum Finden der Zerlegungen verwendet werden, die die kürzeste Behandlungszeit ergeben, um die Gesamtbehandlungszeit zu minimieren und die Lebensdauer der Strahlungsbehandlungsvorrichtung zu erhöhen.

[0058] Die Intensitätskarte kann in Mikrozellen heruntergebrochen werden, die eine andere Abmessung als 5 mm × 5 mm aufweisen, falls eine unterschiedliche Auflösung gefordert wird. Zum Beispiel kann jede Makrozelle in neun Mikrozellen unterteilt werden, in welchem Fall die Intensitätskarte als zwei orthogonale Intensitätskarten lieferbar ist, die eine Auflösung von 1 cm × 1/3 cm bzw. 1/3 cm × 1 cm aufweisen (siehe zum Beispiel die U.S. Patentanmeldung mit der Seriennummer 09/234,364, auf die bereits oben Bezug genommen wurde). Außerdem kann ein Mehrblattkollimator mit Blättern, die eine andere Breite als 1 cm aufweisen, verwendet werden, und die Größe der entsprechenden Mikrozellen wird 1/n-mal die Blattbreite sein (wobei n eine positive ganze Zahl ist (z. B. 2 oder 3)).

[0059] **Fig.** 16 ist eine Ablaufdarstellung, die einen Prozess zum Definieren und Liefern von Strahlungsbehandlungsfeldern mit einem die Intensität modulierenden Mehrblattkollimator illustriert. In Schritt **200** wird ein Gitter **97** über dem Behandlungsbereich T plaziert (**Fig.** 11 und 16). Wie oben beschrieben wurde, das Gitter **97** enthält bevorzugterweise Zellen, die Seiten aufweisen, die gleich einem integralen Bruchteil (d. h. 1/n, wobei n eine ganze Zahl ist) der Breite der Mehrblattkollimatorblätter entsprechen. In Schritt **202** werden die Zellen zur Bildung von Matrizen gruppiert. In Schritt **203** werden die Matrizen gefiltert, wie es in der U.S. Patentanmeldung mit der Seriennummer 09/457,601 beschrieben ist, damit sie mit dem Zerlegungsprozess kompatibel sind. Jede Matrix wird in orthogonale Matrizen zerlegt (Schritt **204**). Der Kollimator wird dann um die zentrale Achse R in seine optimale Null-Grad-Offset-Position gedreht (Schritt **206**). Mit dem Kollimator in seiner Null-Grad-Offset-Orientierung werden die Blätter longitudinal zum Definieren eines ersten Behandlungsfeldes bewegt (Schritt **208**). Eine Hälfte der vorgeschriebenen Strahlungsdosis wird auf das erste Behandlungsfeld angewandt (Schritt **210**). Der Kollimator wird dann um ungefähr neunzig Grad um die zentrale Achse R gedreht (Schritt **212**) und die Blätter werden zum Definieren eines zweiten Behandlungsfeldes positioniert (Schritt **214**). Die verbleibende Hälfte der Strahlung wird dann mit den für das zweite Behandlungsfeld positionierten Blättern angewandt (Schritt **216**). Die Blätter können auch zum Definieren von zusätzlichen Behandlungsfeldern positioniert werden, falls es durch die Zerlegung der Matrizen erforderlich ist, wie es in **Fig.** 13 gezeigt ist.

Patentansprüche

1. Verfahren zum Liefern von Strahlung von einer Strahlungsquelle an einen Behandlungsbereich (T) unter Verwendung eines Mehrblattkollimators (**80**), mit den Schritten:
Positionieren des Mehrblattkollimators zwischen der Strahlungsquelle und dem Behandlungsbereich zum Blockieren eines Teils der Strahlung, wobei die Blätter (**120, 122**) des Mehrblattkollimators sich longitudinal entlang einer ersten Achse (Y) erstrecken und zum Definieren eines ersten Behandlungsfeldes positioniert sind,
Liefern von Strahlung an das erste Behandlungsfeld,
Drehen des Mehrblattkollimators um eine zentrale Achse (R), die sich im wesentlichen senkrecht zu einer Ebene erstreckt, die mindestens einen Teil der Blätter enthält,
Positionieren der Blätter (**124, 126**) zum Definieren eines zweiten Behandlungsfeldes, und
Liefern der Strahlung an das zweite Behandlungsfeld.
2. Verfahren nach Anspruch 1, bei dem das Drehen des Mehrblattkollimators (**80**) ein Drehen des Kollimators, bis die Blätter sich longitudinal entlang einer zweiten Achse (X), die im wesentlichen senkrecht zu der ersten Achse (Y) ist, erstrecken, aufweist.
3. Verfahren nach Anspruch 1 oder 2, bei dem das Liefern der Strahlung an das erste Behandlungsfeld das Liefern von einer Hälfte einer vorgeschriebenen Strahlungsdosis aufweist, und das Liefern der Strahlung an das zweite Behandlungsfeld das Liefern der verbleibenden Hälfte der vorgeschriebenen Strahlungsdosis aufweist.
4. Verfahren nach einem der Ansprüche 1 bis 3, bei

dem das Positionieren der Blätter das Positionieren derart, daß die Umfangskante des Behandlungsbereiches einen Mittelpunkt der Querkante (**130**) des jeweiligen Blattes schneidet, aufweist.

5. Verfahren nach einem der Ansprüche 1, 2 oder 4, das weiter die Schritte des longitudinalen Bewegens der Blätter (**120, 122**) zum Definieren eines dritten Behandlungsfeldes und des Lieferns von Strahlung an das dritte Behandlungsfeld aufweist.

6. Verfahren nach Anspruch 5, bei dem das Positionieren der Blätter (**124, 126**) zum Definieren des zweiten Behandlungsfeldes das Schneiden des Umfangsrandes des Zielbereiches mit einem Querrand (**130**) des jeweiligen der Blätter in einer Position, die ein Drittel der Breite des Blattes von einem Längsrand des Blattes beabstandet ist, aufweist.

7. Verfahren nach Anspruch 6, bei dem das Bewegen der Blätter zum Definieren des dritten Behandlungsfeldes das Schneiden des Umfangsrandes des Zielbereiches mit dem Querrand (**130**) des Blattes in einer Position, die zwei Drittel der Breite des Blattes von dem Längsrand des Blattes beabstandet ist, aufweist.

8. Verfahren nach einem der Ansprüche 5 bis 7, bei dem das Liefern der Strahlung an das erste, das zweite und das dritte Behandlungsfeld das Liefern von einem Drittel einer vorgeschriebenen Strahlungsdosis an jedes der Behandlungsfelder aufweist.

9. Verfahren nach einem der Ansprüche 1 bis 8, das weiter die Schritte des Teilens des Behandlungsbereichs in eine Mehrzahl von Zellen (**102**), die jeweils einen definierten Behandlungsintensitätspegel aufweisen, des Gruppierens der Zellen zur Bildung einer Mehrzahl von Matrizen (**114**), wobei jede der Matrizen mindestens eine Abmessung, die ungefähr gleich zu der Breite eines Kollimatorblattes ist, aufweist, und des Zerlegens von jeder der Matrizen in orthogonale Matrizen (**116, 118**) aufweist.

10. Verfahren nach Anspruch 9, bei dem Strahlung mit einer Auflösung, die der Hälfte der Blattbreite entspricht, geliefert wird.

11. Verfahren nach Anspruch 9 oder 10, das weiter die Schritte des Zuordnens eines Intensitätspegels, der größer als Null ist, zu jeder Zelle (**102**), die als Ganzes innerhalb des Behandlungsbereiches liegt, und des Zuordnens eines Intensitätspegels von Null zu jeder Zelle, die komplett außerhalb des Behandlungsbereiches liegt, aufweist.

12. Verfahren nach Anspruch 11, das weiter die Schritte des Zuordnens eines Intensitätspegels größer als Null zu jeder Zelle (**102**), bei der eine Hälfte oder mehr ihrer Fläche innerhalb des Behandlungsbereichs liegt, und des Zuordnens eines Intensitätspegels von Null zu jeder Zelle, bei der weniger als eine Hälfte ihrer Fläche innerhalb des Behandlungsbereichs liegt, aufweist.

13. Verfahren nach einem der Ansprüche 9 bis 12, bei dem die Kollimatorblätter eine Breite von 1 cm aufweisen und die Zellen ungefähr 1 cm × 5 mm sind.

14. Verfahren nach einem der Ansprüche 1 bis 13, das weiter den Schritt des Teilens des Behandlungsbereiches in zwei oder mehr Abschnitte aufweist, wobei der Bereich entlang einer Linie geteilt wird, die sich im wesentlichen senkrecht zu einer Richtung der Bewegung der Blätter erstreckt.

Hierzu 11 Seite(n) Zeichnungen

- Leerseite -

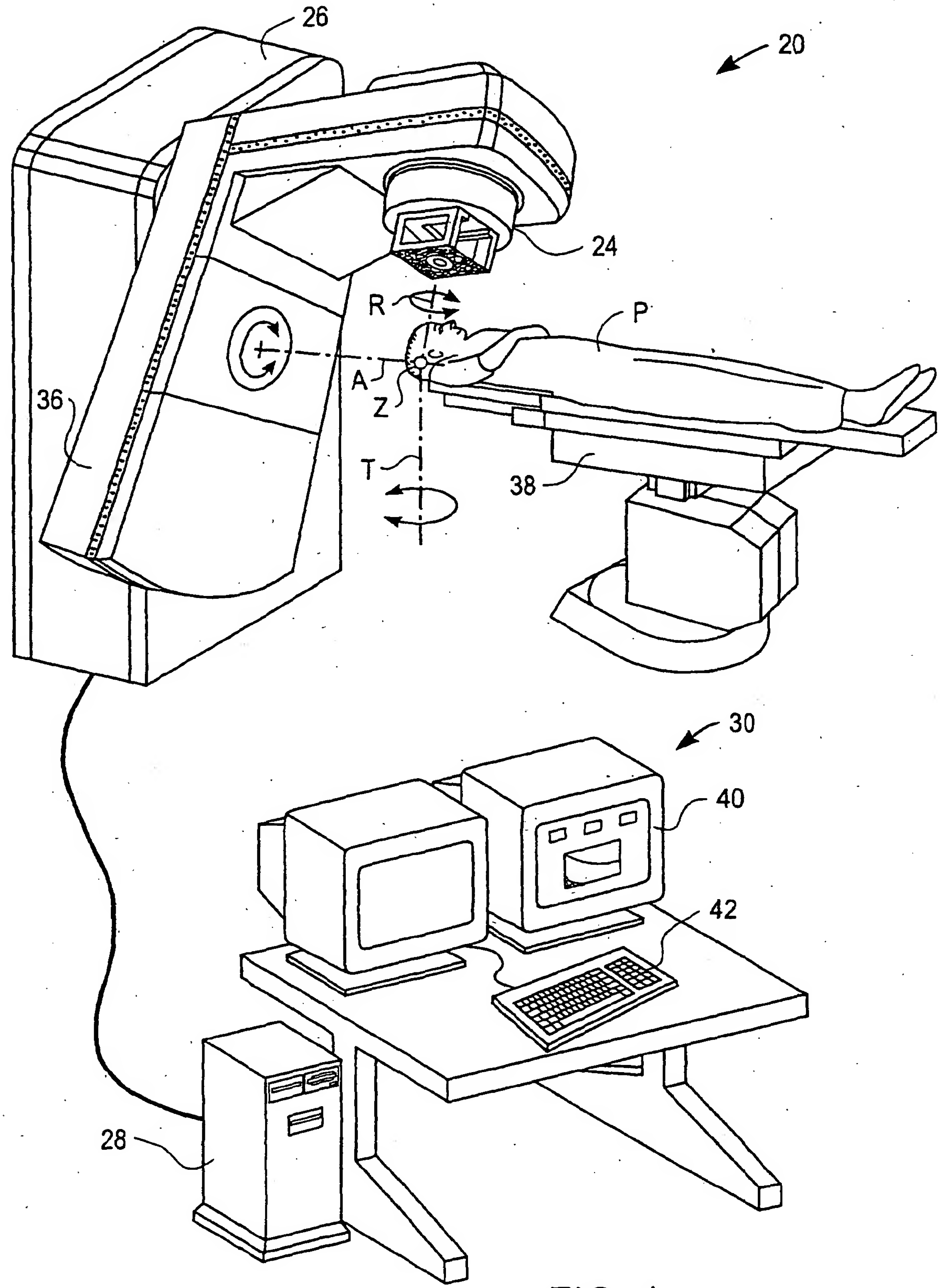

FIG. 1

Nummer: DE 101 40 100 A1
Int. Cl.[7]: A 61 N 5/10
Offenlegungstag: 28. März 2002

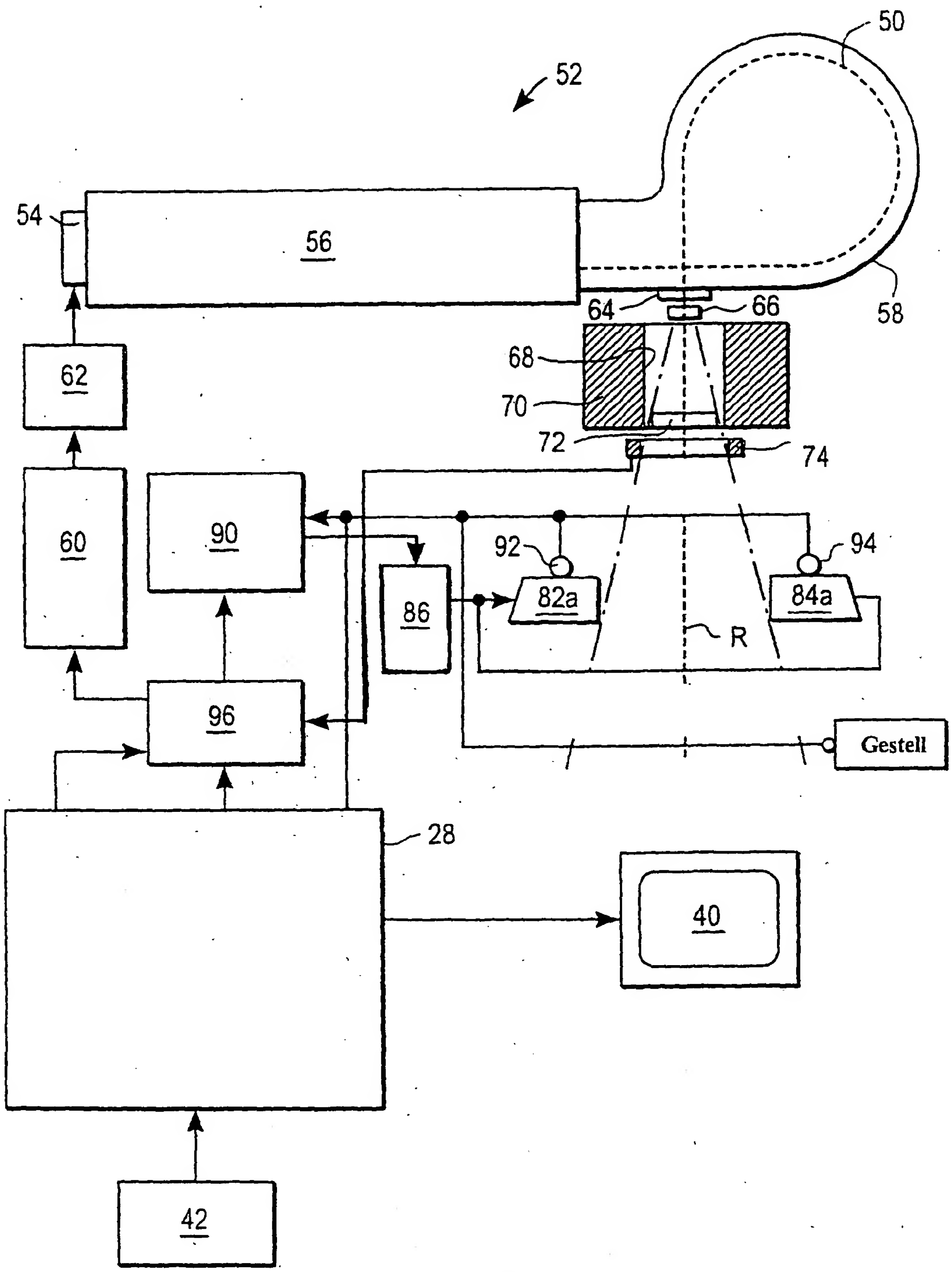

FIG 2

Nummer: DE 101 40 100 A1
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Offenlegungstag: 28. März 2002

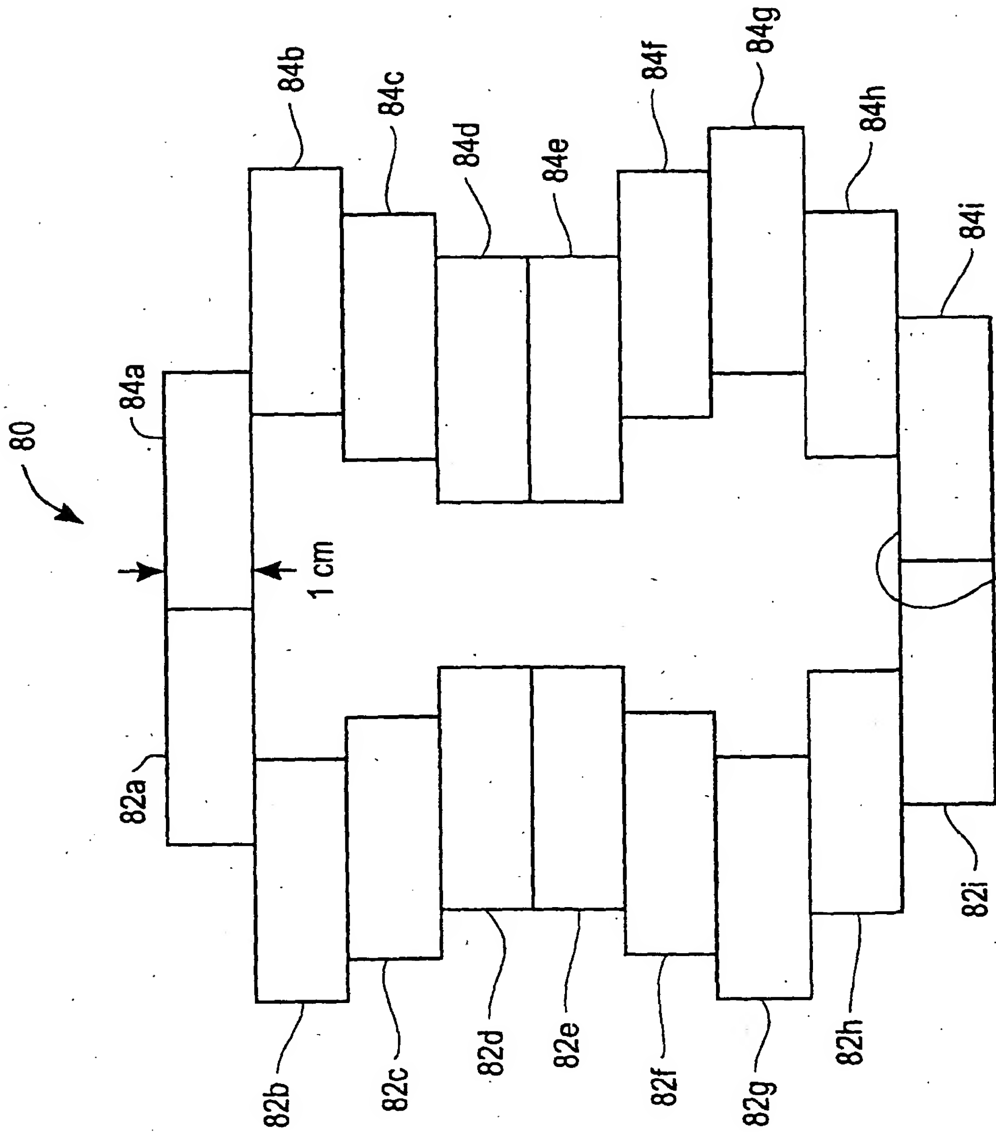

FIG. 3

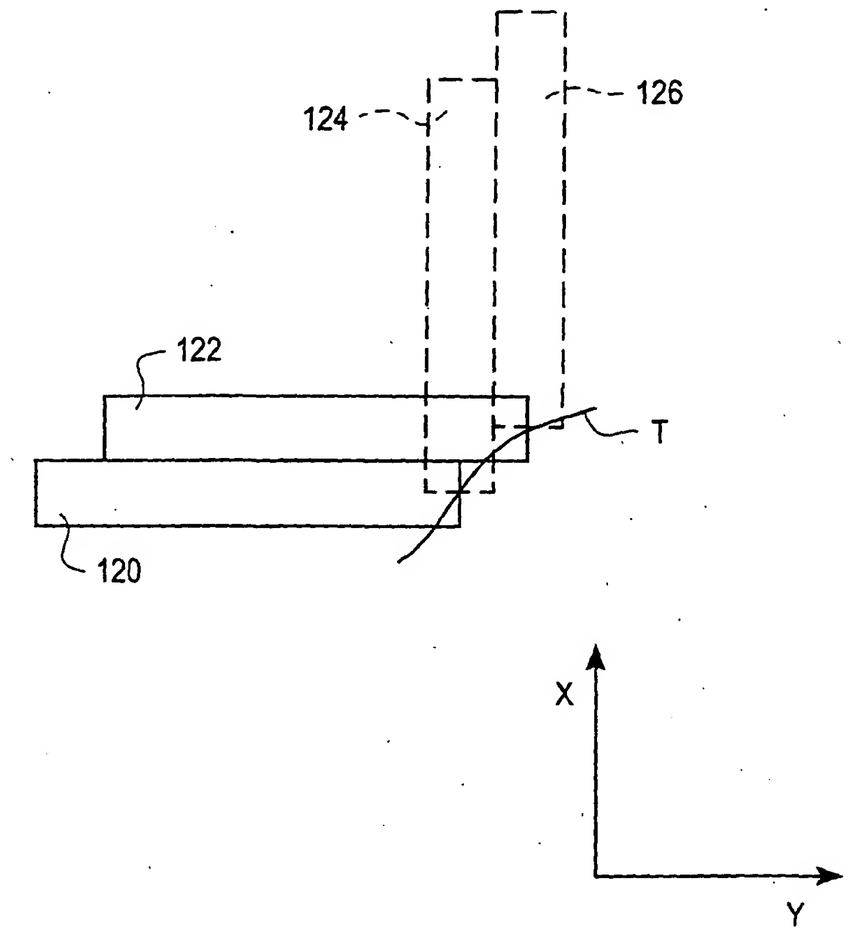

FIG. 4

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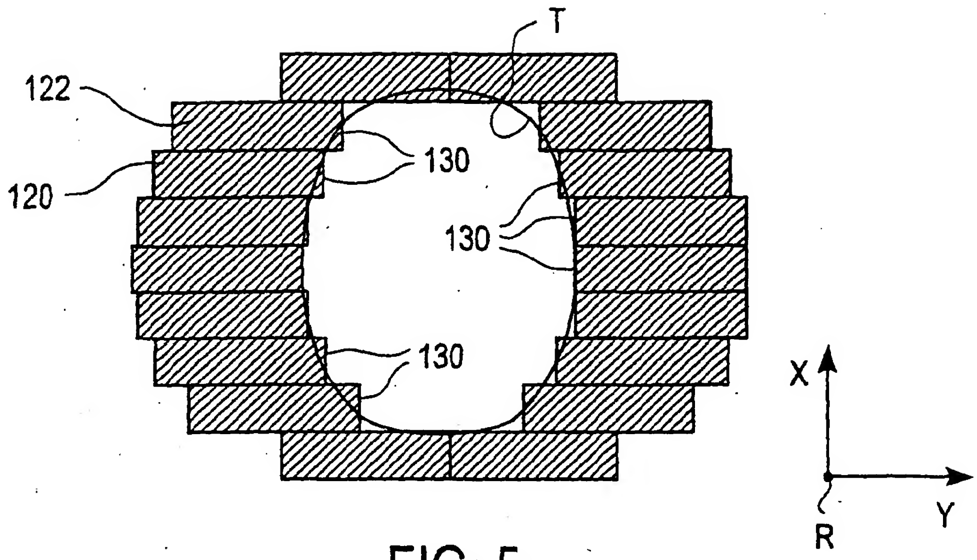

FIG. 5

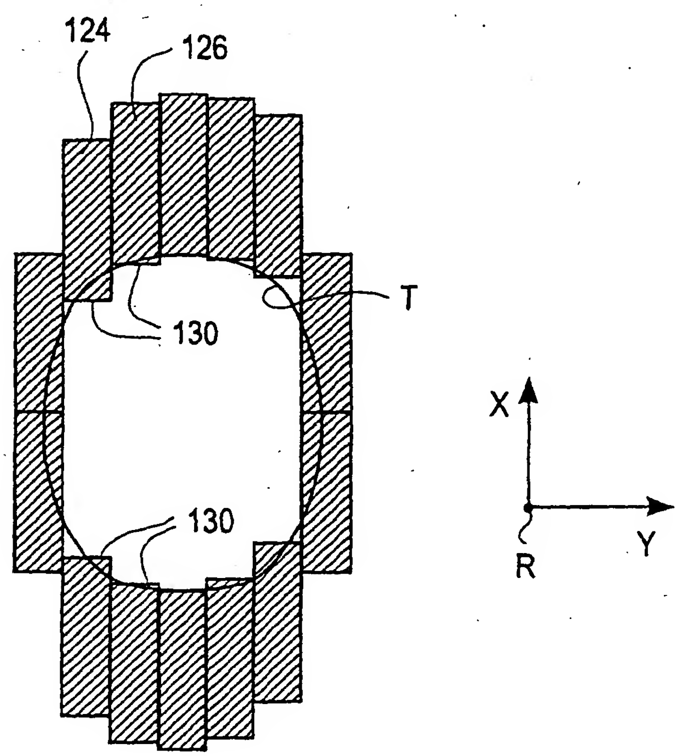

FIG. 6

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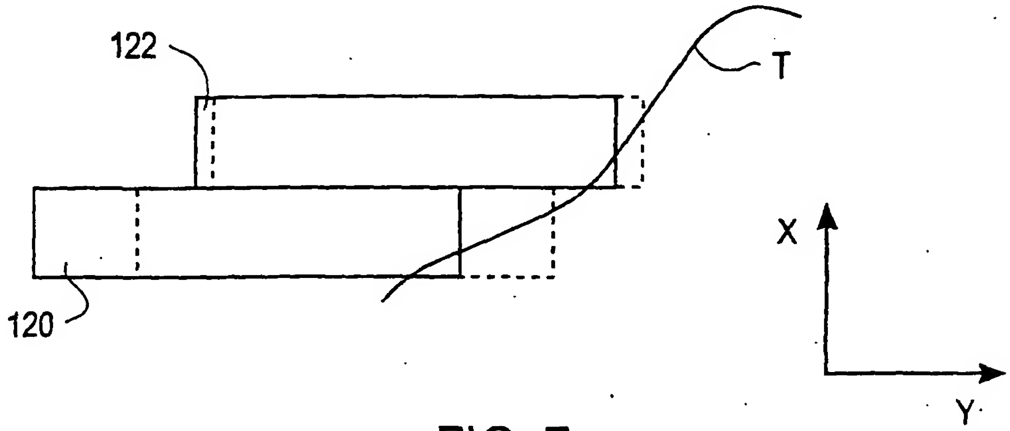

FIG. 7

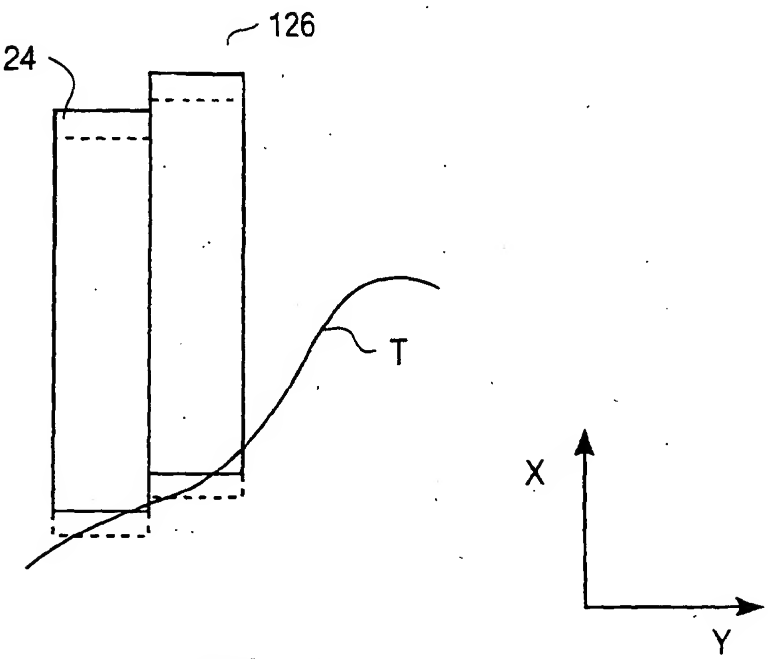

FIG. 8

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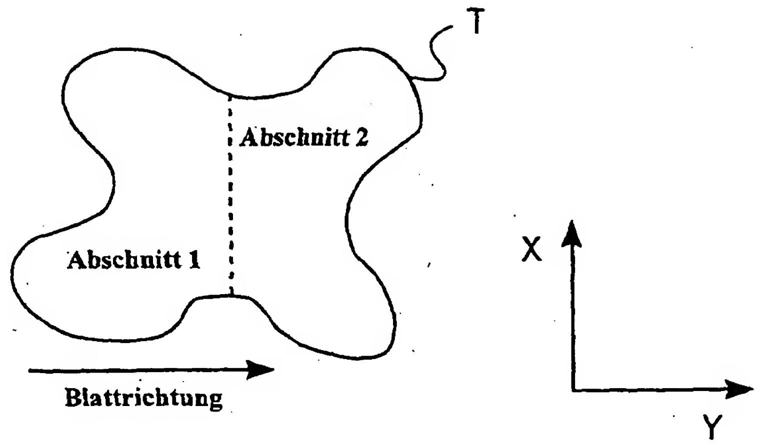

FIG. 9

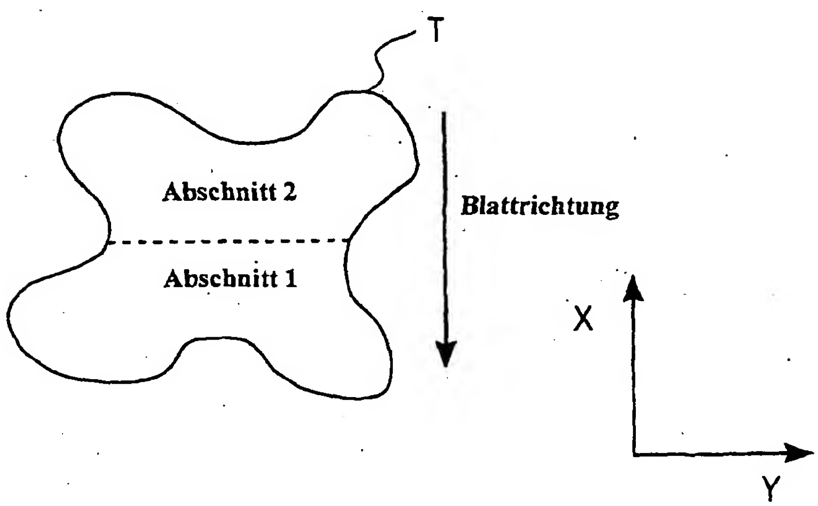

FIG. 10

T

97

0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0
0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FIG. 11

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Int. Cl.[7]: A 61 N 5/10
Offenlegungstag: 28. März 2002

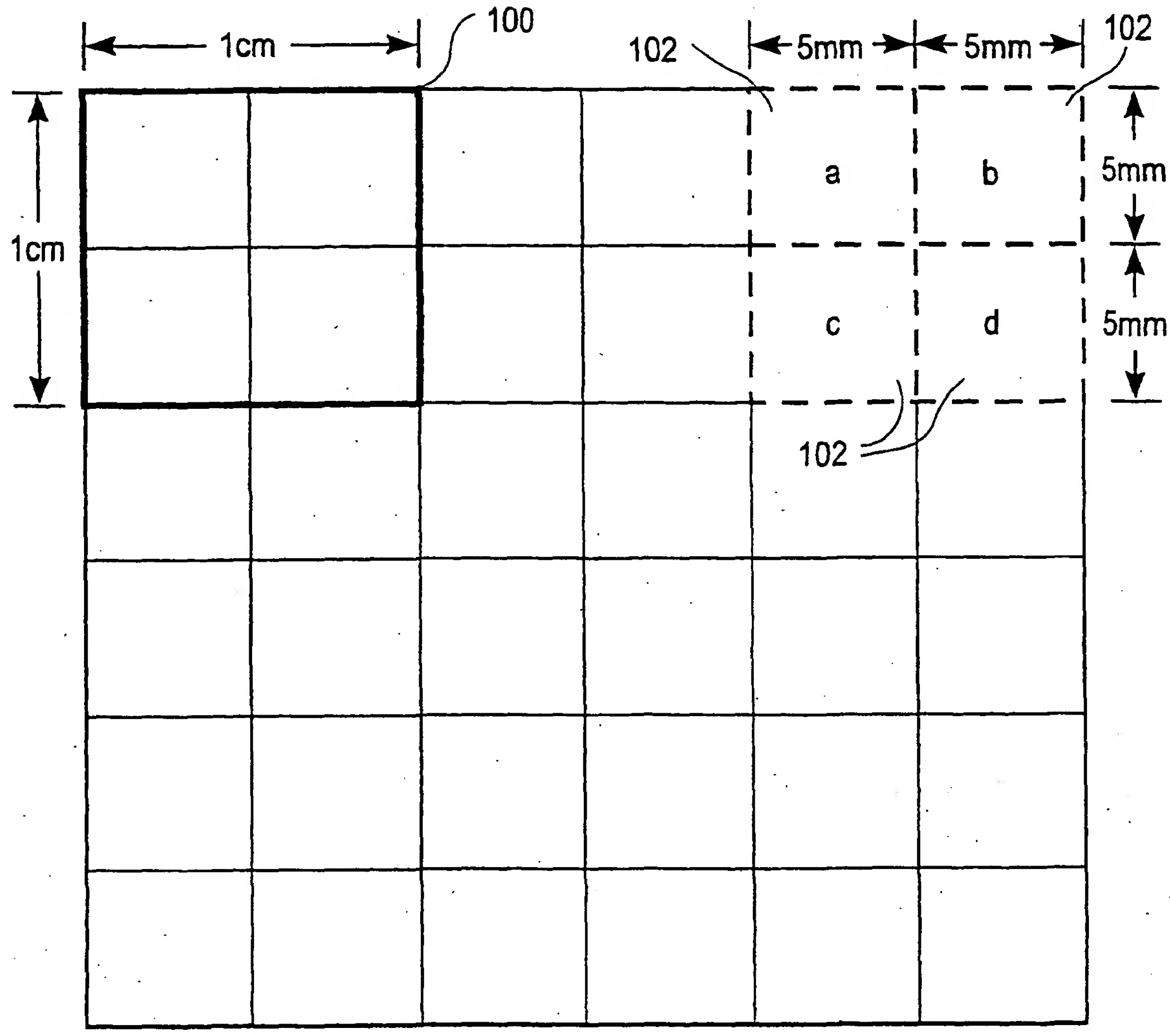

FIG. 12

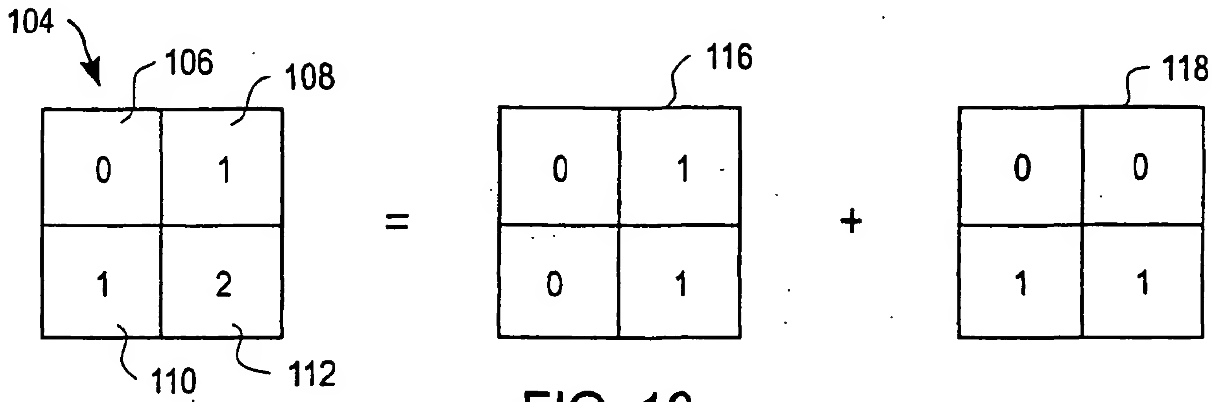

FIG. 13

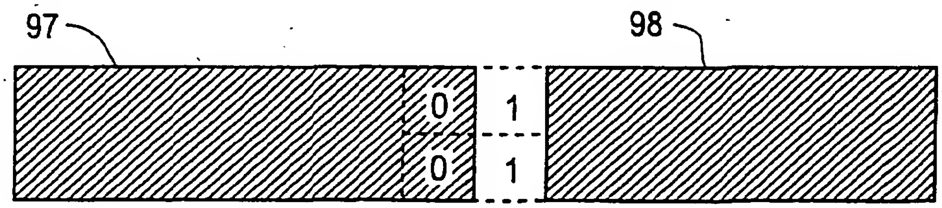

FIG. 14

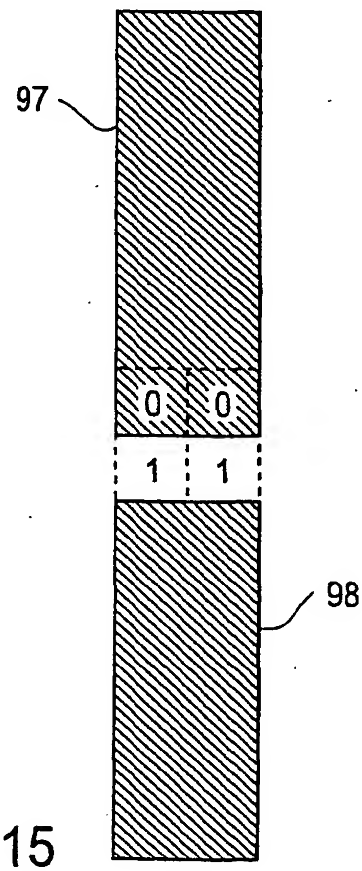

FIG. 15

Nummer: DE 101 40 100 A1
Int. Cl.⁷: A 61 N 5/10
Offenlegungstag: 28. März 2002

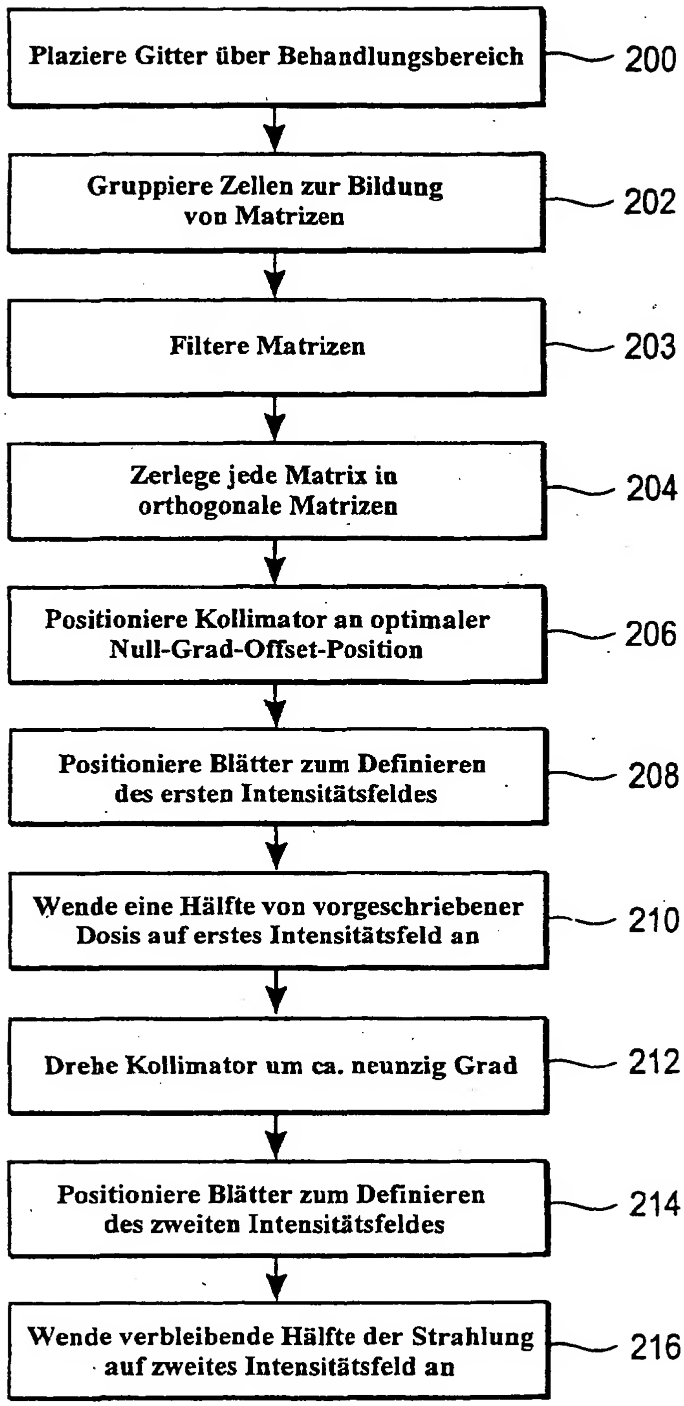

FIG. 16

US005332908A

United States Patent [19]

Weidlich

[11] **Patent Number: 5,332,908**

[45] **Date of Patent: Jul. 26, 1994**

[54] **METHOD FOR DYNAMIC BEAM PROFILE GENERATION**

[75] Inventor: **Georg A. Weidlich**, Concord, Calif.

[73] Assignee: **Siemens Medical Laboratories, Inc.**, Concord, Calif.

[21] Appl. No.: **17,459**

[22] Filed: **Feb. 11, 1993**

Related U.S. Application Data

[63] Continuation of Ser. No. 860,945, Mar. 31, 1992, abandoned.

[51] **Int. Cl.**[5] **G21K 1/04**

[52] **U.S. Cl.** **250/492.1**; 378/65; 378/152; 250/505.1

[58] **Field of Search** 250/492.1, 505.1, 492.3; 378/65, 152, 151

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Primary Examiner—Jack I. Berman
Attorney, Agent, or Firm—Lawrence C. Edelman

[57] **ABSTRACT**

A method for applying a radiation treatment with an arbitrary isodose profile is disclosed. The treatment apparatus has a radiation source which generates a radiation beam with an axis. The apparatus also includes a collimator having a plurality of independently movable plates disposed in the path of the radiation beam and oriented in a direction perpendicular to said beam axis. Each set has two movable plates. Control signals are generated. Two plates within a set of plates are actuated independently in orthogonal directions during the treatment, in response to the control signals, causing the beam to change in width. The intensity of the beam is changed as a function of the position of the plates to generate an arbitrary beam profile. Exemplary profiles which may be generated included rotationally symmetric parabolic profiles and flat profiles.

17 Claims, 5 Drawing Sheets

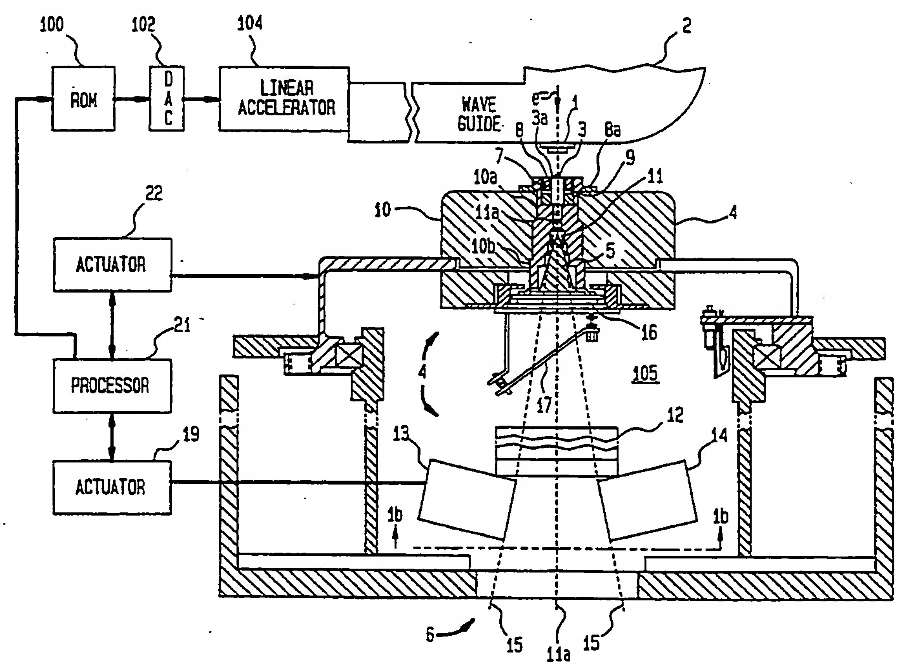
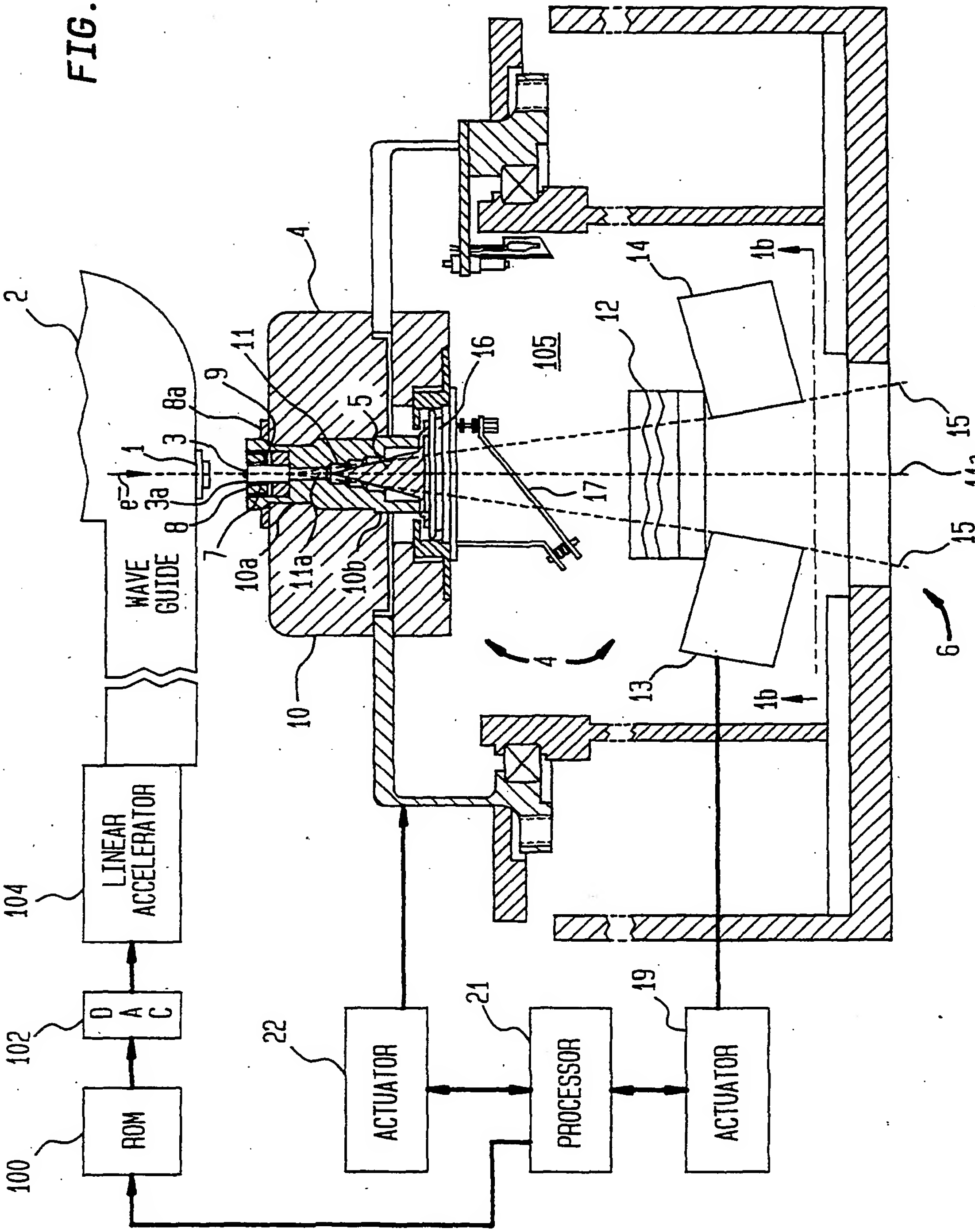


FIG. 1a



WAVE GUIDE
LINEAR ACCELERATOR
D A C
ROM
ACTUATOR
PROCESSOR
ACTUATOR
2
4
e⁻
1
3
3a
8
8a
9
11
5
16
7
10a
11a
10b
10
105
12
14
1b
1b
13
15
15
11a
17
6
100
102
104
22
21
19

FIG. 1b

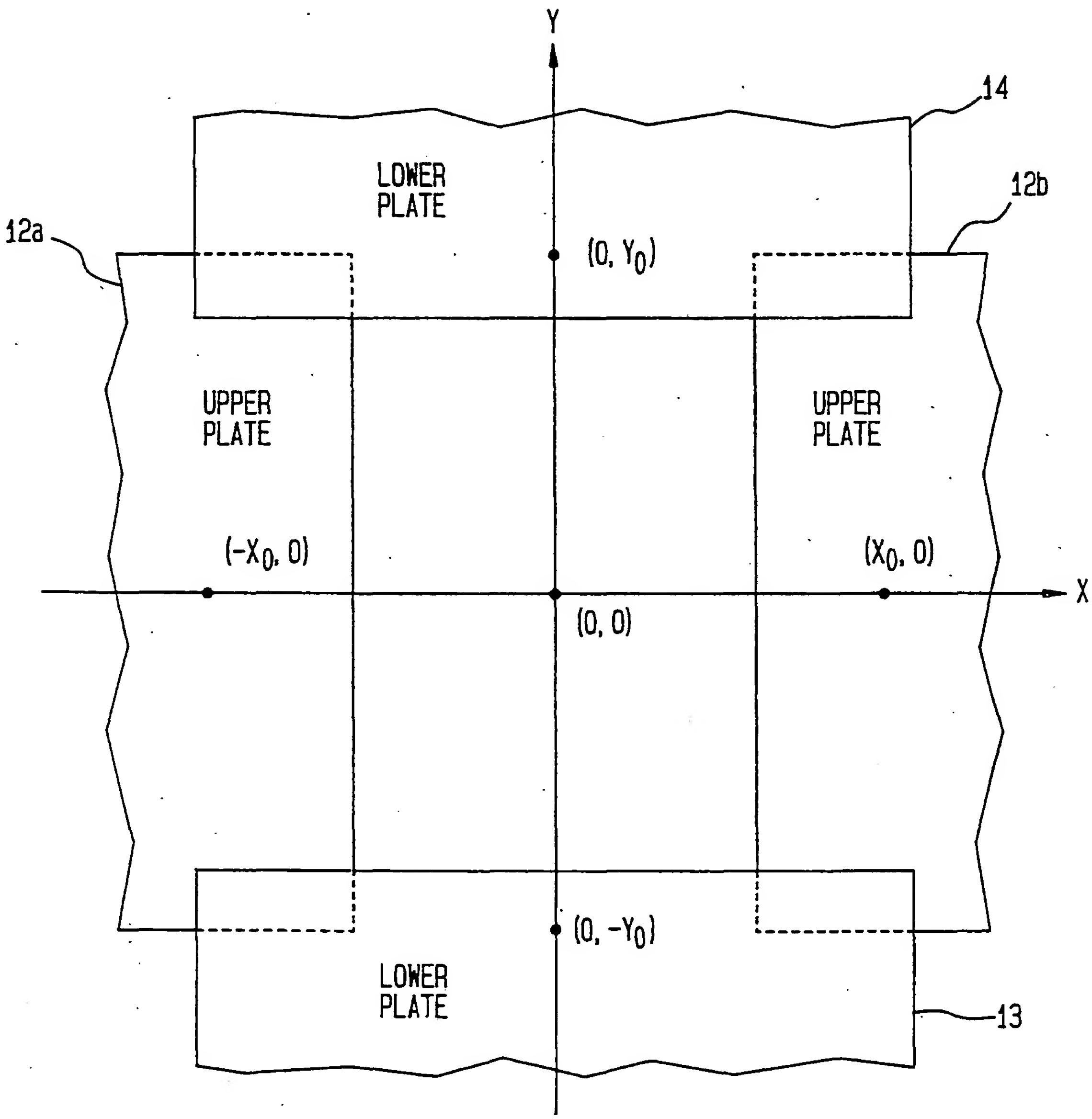

Y
14
LOWER
PLATE
12b
12a
(0, Y_0)
UPPER
PLATE
UPPER
PLATE
($-X_0$, 0)
(X_0, 0)
X
(0, 0)
(0, $-Y_0$)
LOWER
PLATE
13

FIG. 2a
(PRIOR ART)

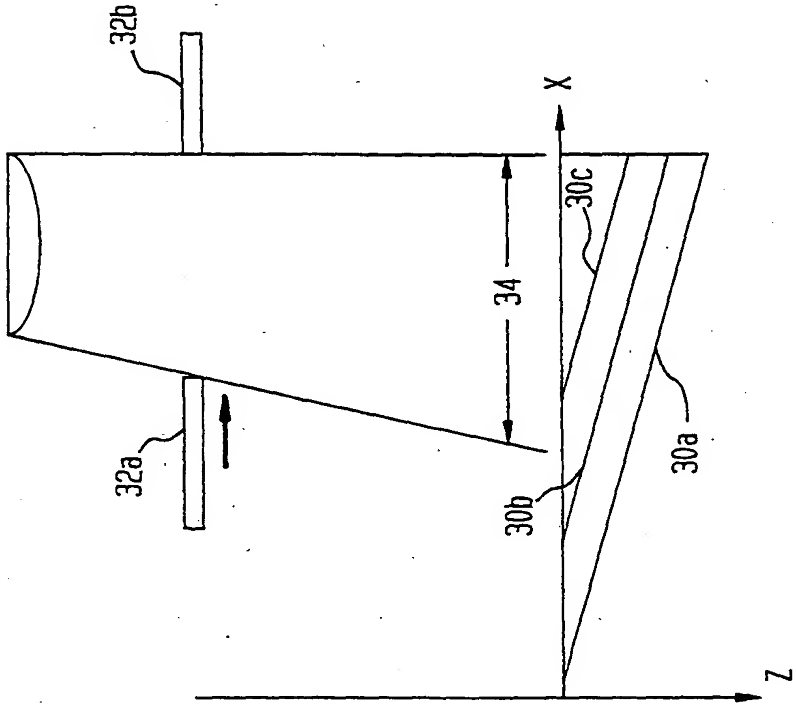


FIG. 2b
(PRIOR ART)

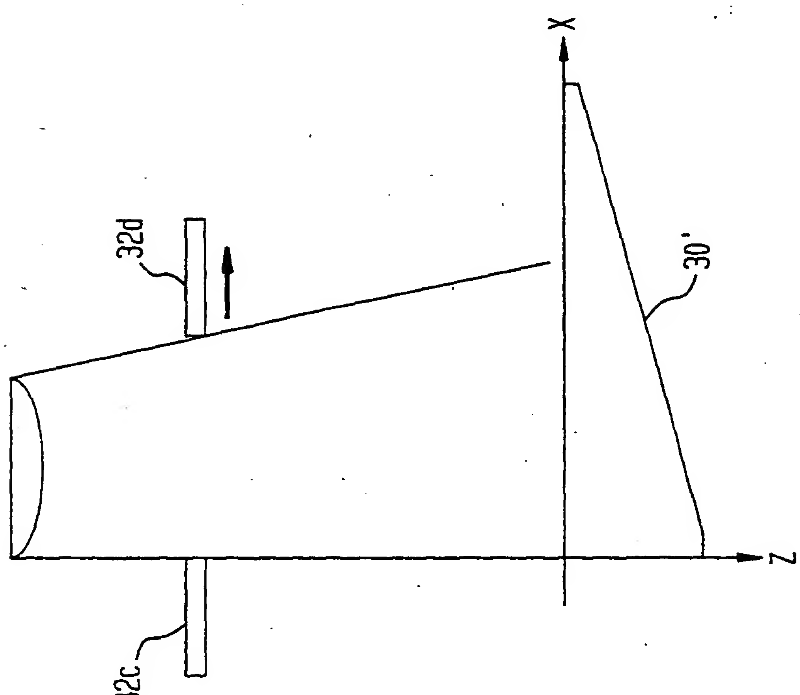


FIG. 3a

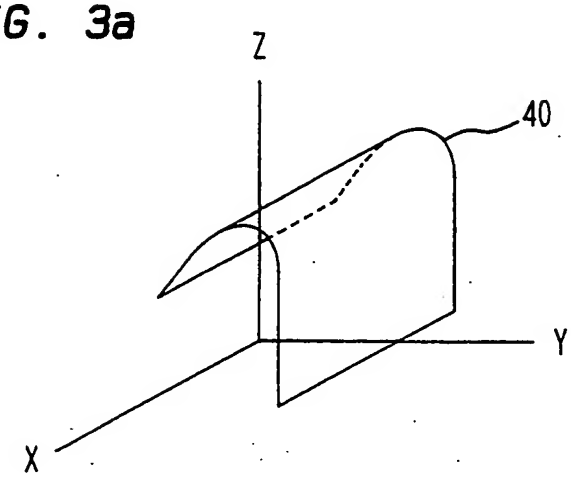


FIG. 3b

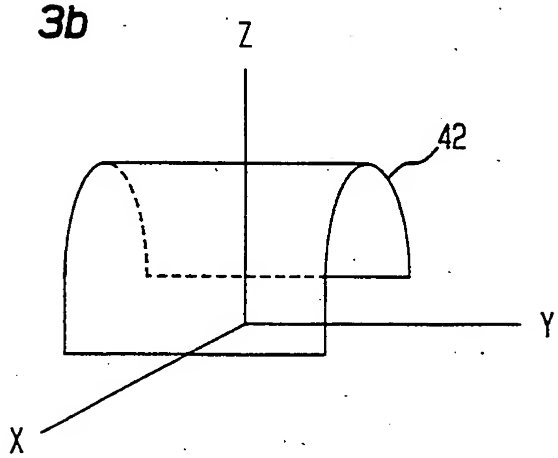


FIG. 3c

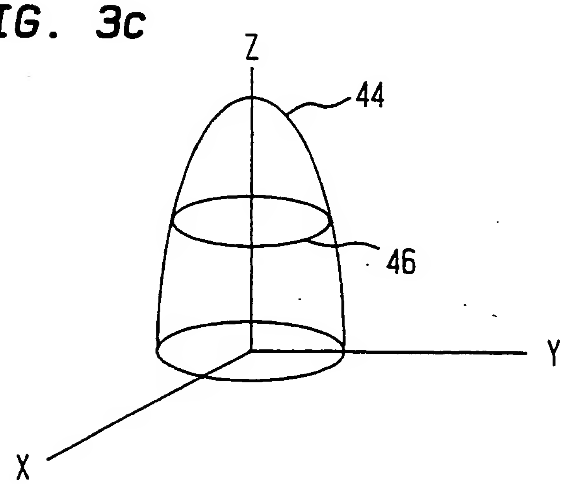


FIG. 4

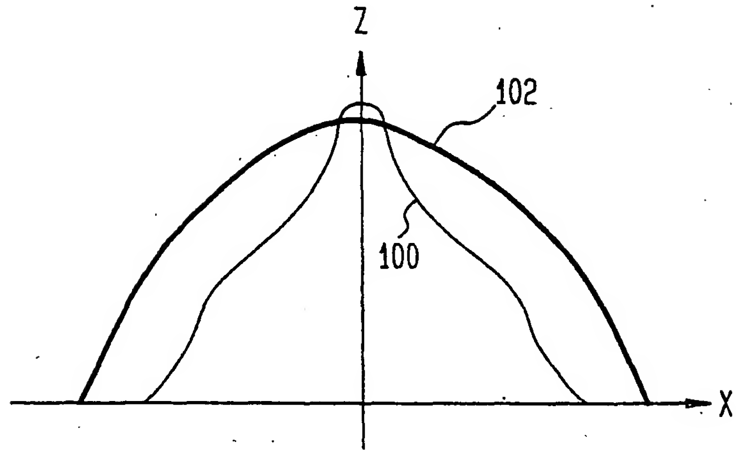


FIG. 5a

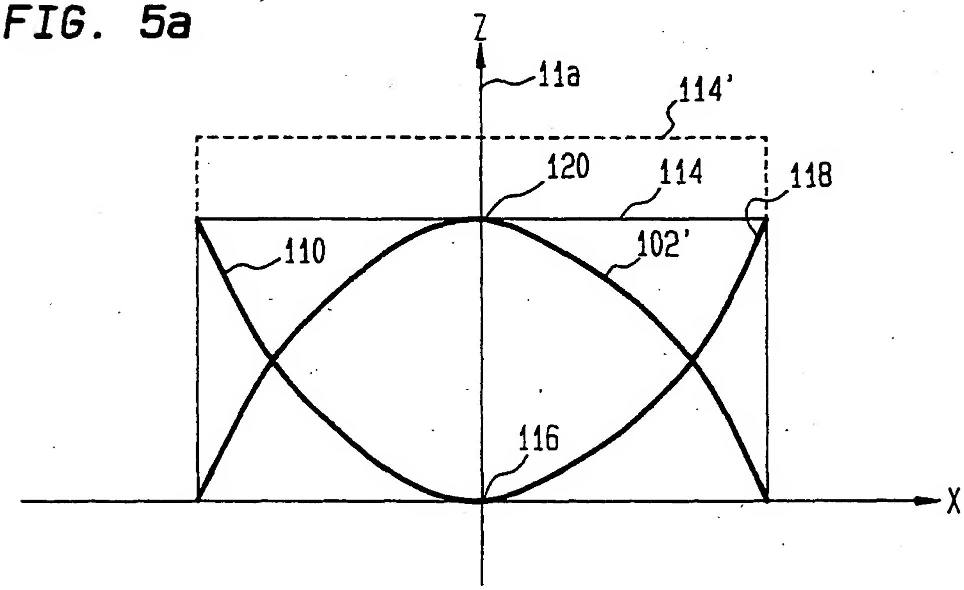


FIG. 5b

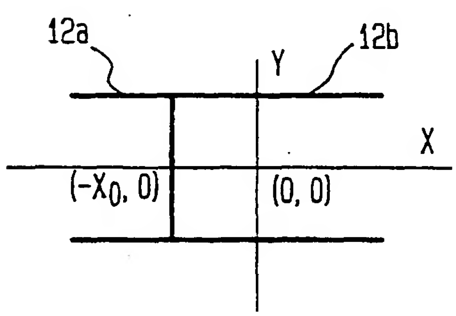
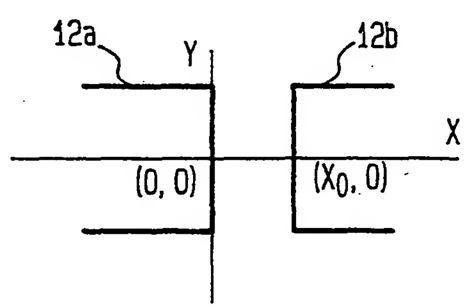


FIG. 5c



METHOD FOR DYNAMIC BEAM PROFILE GENERATION

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation of Ser. No. 07/860,945 filed Mar. 31, 1992, now abandoned. Furthermore, Ser. No. 07/860,959 filed Mar. 31, 1992 is a related application.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the field of linear accelerators, and in particular to computer controlled radiation therapy systems.

2. Description of the Prior Art

Radiation therapy has been used extensively as a method for treating cancer patients, either alone, or in combination with surgery and chemotherapy. In typical radiation therapy systems, such as the Mevatron systems available from Siemens Medical Systems, Inc. (Iselin, N.J.), a radiation source is housed in a structure called a gantry. The apparatus includes a conventional microwave power source such as a klystron, and an accelerator structure, which may be a travelling wave or standing wave device. The accelerator produces an electron beam, which is steered through a collimating head mounted on the gantry and directed at the region to be treated. For more superficial tumors, the electron beam itself is used for treatment, because it has less impact on deeper tissue. For deeper tumors, however, high energy X rays are preferred for their penetrating power. To generate the X rays, the same electron accelerator may be used with the addition of a target made of heavy metal (e.g., gold or tantalum) placed in the path of the electron beam. The target emits a continuous X ray Bremsstrahlung spectrum when struck by the electron beam.

The gantry can rotate about a gantry axis which extends from the head to the foot of a treatment couch on which the patient lies, so that the radiation can enter the patient from different angles. The radiation beam coming from the accelerator is always directed through, and centered on, the gantry axis.

In applying radiation to the patient, two competing objectives are present: eliminating the malignant cells in the target region, and avoiding complications due to application of radiation to surrounding tissues. To avoid these complications, lower doses have often been applied to the targeted tumor cells than would be applied if complications were not considered, lowering the probability of successful cancer elimination. To protect surrounding tissues without compromising the treatment, it is desirable to tailor the radiation dosage to match the size, shape and location of the malignant region.

Several methods have been used in radiation therapy systems to improve control of the dosage distribution. One such method is to shape the beam profile. The "raw" beam which leaves the target has a non-uniform intensity. It is known to balance or compensate the dosage in any given space-angle range of the radiation leaving the target by placing a compensating absorber in the beam path. U.S. Pat. No. 4,109,154 to Taumann discusses an electron accelerator in which a compensating absorber is used to shape the beam profile. The absorber absorbs overly intense radiation in the center of the beam cone.

A paper by Mantel, et al. entitled "Aut matic Variation of Field Size and Dose Rate in Rotation Therapy" 2 J. Radiat. Oncol. Biol. Phys. 697 (1977) discusses a technique for changing the field size and dose rate used during rotation therapy. The gantry (and the nclosed beam forming head) rotates around the patient, so that the beam is applied from several angles. The field size and dose rate are varied as functions of the gantry angle. In this technique, the field size is adjusted in one dimension by moving a set of collimator aperture plates, or jaws, which define the beam aperture (and control the beam width), and simultaneously varying the dose rate during rotation in accordance with values selected by a computer program. The result is a more uniform dose distribution inside the target volume, and reduced dose outside that volume.

U.S. Pat. No. 4,140,129 to Heinz et al discloses a beam defining system for an electron accelerator, having an adjustable collimator and an accessory holder, to which an electron applicator is attached. The electron applicator has a wall which encloses the electron beam cone from the collimator, and an additional frame-shaped limiting aperture in order to limit the electron beam cone at the edges which face away from the beam defining system. The scattered or secondary electrons in the marginal region of the beam cone are substantially blocked by the limiting aperture. The electrons which are thus blocked have lower energy levels and, so, do not contribute to higher dosage performance deep within the patient. Thus, this device reduces undesirable irradiation of the skin surrounding the target.

U.S. Pat. Nos. 4,343,997 and 4,359,642 to Heinz, which are hereby incorporated by reference for their teachings on radiation treatment devices, describe a collimator assembly which may be used to limit or define X-ray cones of various sizes in an electron beam accelerator. A flattening filter is used with this technique to flatten the X-ray density profile. Flat dosage is achieved through the use of a collimator shielding block and one of a plurality of insert pieces or bushings which are interchangeable with one another to produce different cone angles for irradiating different sized areas.

Another method of controlling the dosage profile is to vary the size of the beam aperture. A paper by Kijewski, et al. entitled, "Wedge shaped Dose Distribution by Computer Controlled Collimator Motion" 5 Med. Phys. 426 (1978) discusses the use of a defined plate (jaw) motion to obtain a wedge-shaped isodose curve (the set of points which receive the same dose of radiation) during irradiation. FIG. 2*a* shows isodose profiles 30*a–c* achieved by this technique. The treatment begins with two collimator plates 32*a*, 32*b* separated from one another. After a predetermined time interval, plate 32*a* is moved towards plate 32*b*, which remains stationary. The movement continues until the plates meet. This causes the beam width 34 to become narrower as the treatment continues. The isodose curves 30*a–c* are deeper in the region near the stationary plate, which is exposed to radiation the longest. Such wedge shaped isodose curves may be desired in radiation therapy to adjust to anatomical conditions of the subject. A similar result may be achieved by beginning with closed plates and opening the plates. FIG. 2*b* shows an isodose curve in which the plates 32*c*, 32*d* begin in the closed position.

U.S. Pat. No. 5,019,713 to Schmidt discusses a radiation therapy device in which a movable aperture assembly and a non-movable filter body are combined to allow the isodose curve in the object of irradiation to rise or fall in the opening direction. At the beginning of the treatment, the plates are closed, and one plate begins to move away from the other (stationary) plate. The absorptance of the filter varies across its length. The cumulative radiation dose received at any point varies as a function of both the filter characteristics and the distance from the stationary plate, making possible non-monotonic isodose curves which vary in one dimension. For example, if the portion of the filter closest to the stationary plate has a higher absorptance, the isodose curve will have an inverted U-shape.

A paper by Levene, et al. entitled, "Computer Controlled Radiation Therapy" 129 Radiol. 769 (1978) discusses variation of dose rate, gantry angle and collimator plate position to achieve the known "arc wedge" technique. A paper by Chin et al. entitled, "Dose Optimization with Computer Controlled Gantry Rotation, Collimator Motion and Dose Rate Variation" 9 J. Radiat. Oncol. Biol. Phys. 723 (1983) discusses methods by which continuous irradiation is simulated by summation of a large number of discrete stationary beams. Dose rate, gantry angle and collimator plate positions are varied among the beams. These methods achieve isodose contours which might not be attainable using a single stationary beam.

It is noted that the Levene et al. and Chin et al. papers relate to a conformal radiation treatment which conforms the field profile and dose rate to a target volume using gantry rotation.

While some of these devices can produce a number of different radiation contours, the apparatus and methods used may be relatively cumbersome and time consuming.

SUMMARY OF THE INVENTION

In accordance with the present invention, an exemplary system and method are provided for controlling the isodose profile of radiation treatment apparatus, in order to provide a rotationally symmetric profile. The system includes an electron accelerator which generates a photon beam. The accelerator has a collimator assembly operating under computer control. The collimator assembly includes a plurality of movable plates mounted to a rotatable collimating head. The plates are oriented in a direction perpendicular to the longitudinal axis of the beam, so that the beam width is defined by the relative positions of the plates.

The plates are actuated during the radiation treatment, under computer control, to vary the beam width defined by the opening formed between the plates according to a predetermined plate motion function which is both continuous and continuously derivable to achieve a desired beam profile without rotation of the longitudinal axis of the beam.

According to one aspect of the invention, the treatment is divided into two parts. During each part, two movable plates are first moved together from an open position, and then opened from a closed position or vice-versa. The direction of motion of the plates during the second part of the treatment is perpendicular to the direction of plate motion during the first part. This may be accomplished by rotating the collimating head ninety degrees at the completion of the first part of the treatment, or by using a second set of movable plates, which are orthogonal to the first set.

According to a second aspect of the invention, a different set of plate movements are used to generate a beam profile with a flat isodose curve, without the use of a flattening filter. This is accomplished by opening the plates from the edge of the treatment region towards the center axis on each side of the beam axis. The same sequence is repeated using the second set of collimator plates, which move in a perpendicular direction. In a further exemplary embodiment, instead of using the second set of plates, the collimator is rotated ninety degrees and the series of plate movements are repeated using the first set of plates.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1*a* is a cross-sectional view, partly in block diagram form of a beam defining system of radiation treatment apparatus which includes an embodiment of the present invention.

FIG. 1*b* is a cross-sectional view, taken perpendicular to the beam axis which shows the beam-defining jaws of the system shown in FIG. 1*a*.

FIGS. 2*a* and 2*b* are graphs of radiation intensity versus distance which show typical wedge shaped isodose profiles produced by prior art systems.

FIGS. 3*a* and 3*b* are graphs of radiation intensity versus distance which show exemplary parabolic isodose profiles that may be generated by the system shown in FIG. 1.

FIG. 3*c* is a graph of radiation intensity versus distance which shows the effective isodose profile formed by summing the profiles shown in FIGS. 3*a* and 3*b*.

FIG. 4 is a graph of an isodose curve (102) and radiation intensity versus distance (100) which shows the unfiltered beam profile produced by the system shown in FIG. 1*a*.

FIG. 5*a* is a graph of an isodose curve which shows a flattened beam profile generated by the system shown in FIG. 1.

FIGS. 5*b* and 5*c* are cross-sectional views, taken perpendicular to the beam axis which show the motion of the beam-defining jaws used to produce the beam profile shown in FIG. 5*a*.

DETAILED DESCRIPTION

FIG. 1 shows an exemplary embodiment of the beam defining system 6 of a medical linear accelerator in accordance with the present invention. An electron accelerator which includes a linear accelerator **104** and a standing wave guide 2 has an exit window **1**, through which an electron beam e− is transmitted to a collimator assembly **105**. The collimator assembly **105** includes a target 3 and electron absorber **9** for generating an X ray beam. The generated beam is substantially free of unabsorbed electrons. The target 3 and absorber **9** are mounted within a carrier plate **8** of the assembly **105**. The target 3, absorber **9** and carrier plate **8** may be removed from the apparatus if desired, to use the electron beam itself for treatment (e.g., for superficial treatment) instead of X rays. The term radiation beam will be used to refer to either an electron beam or an X ray beam.

The intensity of the electron beam and thus of the X ray beam is controlled by the processor **21**. In response to address values provided by the processor **21**, a read-only memory (ROM) **100** applies programmed digital values to a digital-to-analog converter (DAC) **102**. The

DAC 102 converts the digital values into control voltages for the linear accelerator 104. In response to different control voltages values, the linear accelerator produces bursts of electrons at respectively different pulse rates (commonly referred to as PRF). Bursts produced at a relatively high rate generate a more intense beam of radiation (i.e. a higher dose rate) than bursts at a relatively low rate. In the exemplary embodiment of the invention, the processor 21 controls the intensity of the X ray beam during a treatment to generate different beam profiles.

The radiation beam has a central axis 11*a*. The beam collimating block 4 is disposed in the path of the radiation, directly below the carrier plate 8. The beam collimating block includes a thick walled collimator shielding block or collimator 10. The collimator 10 houses an insert 10*a*, to which a flattening filter 5 may be mounted. The flattening filter 5, when used, symmetrically attenuates the radiation more towards the center of the beam, so that the intensity of the radiation is approximately constant across the beam width. Filter 5 is rotationally symmetric and is centered relative to axis 11*a*.

The collimator assembly 105 has two pairs of tungsten X ray shielding plates, 12*a*, 12*b*, and 13, 14 which are adjustable relative to the axis 11*a*. In the system shown in FIG. 1*a*, plate 12*a* (not visible in the Figure) moves into the page while plate 12*b* moves out of the page. Plates 13 and 14 move to the left and right respectively. Thus, each pair of plates 12*a*, 12*b* and 13, 14 is movable along a single axis, referred to as the X and Y axes, respectively. The X and Y axes and the beam axis 11*a* form an orthogonal set. The inner edges of the plates define the radiation field edge, and therefore, the positions of the four plates determine the radiation field size. The plates 12*a*, 12*b*, 13 and 14 are shown in a view along the Z axis in FIG. 1*b*. At least two of the plates are capable of crossing axis 11*a*. The collimator is mounted for rotation about the beam axis.

In order to provide the desired accuracy for the speed and position of the collimator plates 12, 13, 14, the plate positions are controlled by an automatic drive unit 19 under computer 21 control. This drive unit may be, for example, a conventional numerically controlled servo system which may use either conventional servo motors or stepper motors to control the positions of the jaws 12*a*, 12*b*, 13 and 14.

In the exemplary embodiment of the invention, the computer 21 periodically calculates a desired position for at least one of the laws 12*a*, 12*b*, 13 and 14 and applies the desired position to the actuator 19. The actuator, in turn, moves the jaw to the desired position. Using this control scheme, a wide variety of beam profiles may be generated which employ both linear and non-linear jaw-motion functions.

In addition, the processor 21 may cause the entire collimator assembly 105 except for the collimating block 4 to rotate by 90° (i.e. counter-clockwise out of the page) and then back to 0° by activating actuator 22.

The invention includes a method for producing a beam with an arbitrary two dimensional isodose contour. An isodose contour is the locus of points in three dimensional space which receive the same total dosage of radiation. The isodose contour is the three dimensional analog of the two dimensional isodose curve.

In some of the embodiments of the invention described below, the apparatus used is as described above, with the flattening filter installed in the collimator. With this filter in place, the beam leaving the collimator is of substantially uniform intensity in both the X and Y directions. Other embodiments of the invention produce a substantially flat beam profile without using a flattening filter.

In order to determine the plate movements which result in the desired dosage being applied, a coordinate system is adopted in which the X and Y axes are located in a plane parallel to the surface of the object which is to be irradiated. The Z axis coincides with the longitudinal axis of the beam and the positive Z direction is the direction of the beam (i.e., pointing from the radiation source towards the treatment area). One set of plates moves in a direction parallel to the X axis and the other set of plates moves in the direction parallel to the Y axis. Equation (1) gives the dosage received for any point (x,y) on the surface at any depth z below the irradiated surface. The attenuation of a two dimensional beam is therefore described by equation (1).

$$D_{(x,y)} = D_{0(x,y)} e^{-\mu z} \tag{1}$$

where:

z=Depth

$D_{0(x,y)}$=Dose deposited at the surface at point (x, y)

$D_{(x,y)}$=Dose deposited at depth z below point (x,y)

μ=Linear attenuation coefficient for the object irradiated

For an isodose contour (i.e., $D_{(x,y)}$=a constant), equation (1) may be solved for the surface beam dosage profile, yielding equation (2).

$$D_{0(x,y)} = D_a e^{\mu z(x,y)} \tag{2}$$

where:

$z_{(x,y)}$=Depth of the isodose contour at (x,y), measured in the z direction

D_a=Dosage on the isodose contour

Equation (2) is differentiated with respect to time in order to determine the dosage rate to be applied to each point to achieve the desired dose profile. Taking the total derivative of equation (2), and simplifying yields equation (3).

$$D_{0(x,y)} = \left| D_a \mu e^{\mu z(x,y)} \left(v_x \frac{d}{dx}[z(x,y)] + v_y \frac{d}{dy}[z(x,y)] \right) \right| \tag{3}$$

where:

$D_{0(x,y)}$=Total dosage rate at the surface at point (x,y)

v_x=dx/dt=relative plate velocity in the X direction

v_y=dy/dt=relative plate velocity in the Y direction

For an isodose contour with an arbitrary shape, the contour $z_{(x,y)}$ will be a function of both X and Y. In order to apply equation (3) for such an isodose contour, the irradiated surface may be divided into a two dimensional array of treatment areas, where an independent radiation field is applied to each area.

To apply the radiation to one of these areas, one set of collimator plates 13, 14 is held still, while the plates 12 in the second pair are moved relative to one another to produce, for example, a wedge shaped area isodose contour. For any area with a flat isodose contour, both sets of plates are held still. For each of these areas, a dosage profile (e.g., constant or wedge shaped) is applied, to approximate the desired isodose contour with a function that is piecewise continuous. This dosage pro-

file may have discontinuities in its derivative at the edges of each treatment area, depending on the profile within each area.

The dosage profile may also be changed by changing the intensity of the beam provided by the linear accelerator **104** and wave guide **2**. As set forth above, this occurs when the processor **21** changes the address value applied to the ROM **100**, thereby changing the PRF of the bursts applied to accelerator **104**.

The method described above for an arbitrary isodose contour may be time consuming if the number of treatment areas is very large. Depending on the nature of the isodose profile in each area, the collimator plates may have to be repositioned when treatment of each area is begun. The method is useful, however if extremely tight control of the isodose contour is desired.

The first exemplary embodiment of the invention includes a method for generating a large and useful class of isodose contours for which the number of independent treatment areas is one. That is, the radiation may be applied in a two part treatment consisting of only one set of plate movements in the X direction and one set of movements in the Y direction. While the first pair of plates is moving in the X direction, the plates oriented parallel to the Y axis remain still (i.e., Y=a constant). Similarly, while the second pair of plates is moving in the Y direction, the plates oriented parallel to the X axis remain still (i.e., X=a constant). Further, to simplify the demands made on the equipment configuration, the plate motions are limited so that the plate speed and the beam intensity variations are continuous functions of time within each of the two sections of the treatment. Any contour which can be described by equation (4) falls into this category.

$$z(x,y)=z_1(x)+z_2(y) \tag{4}$$

where:

$z_1(x)$=a function of x only

$z_2(y)$=a function of y only

Substituting equation (4) into equation (2) and taking the time derivative yields equation (5).

$$D_{0(x,y)} = \left| D_a\mu e^{\mu z_1(x)} e^{\mu z_2(y)} \left\{ v_x \frac{d}{dx} z_1(x) + v_y \frac{d}{dy} z_2(y) \right\} \right| \tag{5}$$

It is desirable to separate equation (5) into two equations, each of which involves only a single variable. If x is held constant, then:

$$e^{\mu z_1(x)} = \text{a constant} = b_x \tag{6}$$

If y is held constant, than

$$e^{\mu z_2(y)} = \text{a constant} = b_y \tag{7}$$

Equation (5) can then be written as follows:

$$D_{0(x,y)} = D_{1(x)}|_{y=const.} + D_{2(y)}|_{x=const.} \tag{8}$$

where:

$$D_{1(x)}|_{y=const.} = C_1 e^{\mu z_1(x)} v_x \frac{d}{dx} z_1(x) \tag{9}$$

$$D_{2(y)}|_{x=const.} = C_2 e^{\mu z_2(y)} v_y \frac{d}{dy} z_2(y) \tag{10}$$

-continued

For any desired isodose contour which can be expressed as the sum of a function of only X plus a function of only Y, equations (8), (9) and (10) may be used to define a treatment which is applied in two distinct parts, one including plate motion in the X direction for a fixed Y direction plate opening, and the other including motion in the Y direction for a fixed X direction plate opening. For each contour, the intensity of the radiation beam applied by the processor **21** is determined by the equations (9) and (10).

An example of such a contour is one in which there is rotational symmetry about the beam axis. For such an isodose contour, any cross section which is perpendicular to the beam axis (i.e., constant depth, z) will be a circle. Such an isodose contour is described by equation (11), in which the locus of points for any fixed value of z define a circle.

$$z(x,y)=C_3-ax^2-ay^2 \text{ for all } x,y \tag{11}$$

In equation (11), the values of C_3 and "a" are determined from the boundary conditions for a particular isodose contour. In the exemplary embodiment, C_3 is the depth of the isodose curve at beam axis (X=0, Y=0).

It is desirable to express equation (11) in a form which can be combined with equations (4). Equations (12), (13) and (14) describe an isodose contour which is separable into functions of X only and Y only, and which have circular cross sections, defining rotational symmetry, consistent with equation (11).

$$z_1(x)=-ax^2+c_x \tag{12}$$

$$z_2(y)=-ay^2+c_y \tag{13}$$

$$C_3=c_xc_y \tag{14}$$

where c_x and c_y are constants

Equation (12) defines parabolas in planes parallel to the plane including the X and Z axes. FIG. 3*b* shows an isodose contour **42** of this form. Any cross section of contour **42** parallel to the X-Z plane is a parabola. Similarly, equation (13) defines parabolas in planes parallel to the plane including the Y and Z axes. FIG. 3*a* shows an isodose contour **40** of this form. FIG. 3*c* shows the isodose contour **44** which is produced by summing the two treatments, with circular cross section **46**. Equations (12) and (13) can be substituted into equations (9) and (10), yielding the desired governing equations (15) and (16) for the beam intensity in terms of the plate motions.

$$D_{1(x)}|_{y=const.} = D_a\mu b_y e^{\mu(-ax^2+cx)} * (2axv_x) \tag{15}$$

$$D_{2(y)}|_{x=const.} = D_a\mu b_x e^{\mu(-ay^2+cy)} * (2ayv_y) \tag{16}$$

Equations (15) and (16) provide the desired relationship between the plate position and velocity and the corresponding intensity of the radiation beam (dose rate) which produce a rotationally symmetric beam profile.

In the exemplary embodiments of the invention described below, the processor **21** moves the plates **12***a*, **12***b*, **13** and **14** with fixed velocities and periodically

determines desirable radiati n beam intensities according to these equations. During each of the treatment schemes described below, only one of the plates **12a**, **12b**, **13** and **14** is in motion at any given time.

Alternatively, the intensity of the radiation beam may be held constant over the treatment and the plates may be moved with variable velocities to pr duce a non-linear beam pr file. To generate a rotati nally symmetric beam profile, for example, the equations 15 and 16 may be solved for v_x and v_y. In this alternative embodiment, the processor **21** causes actuator **19** to periodically move the plates to positions which produce the desired velocity profile.

The first treatment to be described produces a parabolic dose distribution. All of these treatments describe positioning of the jaws **12a**, **12b**, **13** and **14**. This positioning may be more readily understood with reference to FIG. **1b**.

In order to apply this first treatment, the apparatus is initially set up with the flattening filter **5** in place, and the lower collimator plates **13**, **14** positioned at edges of the beam field symmetrically placed about the X axis at coordinates ($X=0$, $Y=-Y_0$) and ($X=0$, $Y=+Y_0$), respectively, where Y_0 is a constant. These plates are held in this position during the first section of the treatment, and for the purposes of the treatment, may be considered "fully open." While plates **13** and **14** may be physically capable of opening further, the positions Y_0 and $-Y_0$ define a preferred beam width. Opening the jaws **13** and **14** any wider this would result in undesirable irradiation of surrounding tissues.

Upper plate **12a** is initially placed along the X axis at ($X=-X_0$, $Y=0$), where X_0 is a constant. Upper plate **12b** is placed at the origin (i.e. $X=0$ and $Y=0$). Plate **12b** is held motionless at the origin, while Plate **12a** is moved towards plate **12b** by the actuator **19**, under control of the processor **21**. It is understood that the application of a radiation beam with constant jaw velocity during this motion would result in the known wedge shaped isodose contour. Instead, during this portion of the treatment, the intensity of the radiation beam is governed by equation (15). The result is that the isodose contour has the desired parabolic cross section, with the maximum radiation dosage at the origin, and zero dosage at ($X=-X_0$).

Once the two plates meet at the origin, the beam is completely blocked. The irradiation of the half of the treatment area for which X is less than zero is complete for the first half (with Y=a constant) of the treatment. The treatment may optionally be interrupted at this point with no effect on the total dosage received at any point.

During the next portion of the irradiation, plate **12a** is held motionless, while plate **12b** moves away from plate **12a** in the positive X direction. The intensity of the radiation beam during this part of the treatment is again controlled by the processor **21** to follow equation (15). The second portion of the irradiation deposits a beam profile on the positive side of the X axis, completing the desired parabolic cross section, with the maximum radiation dosage at the origin, and zero dosage at ($X=+X_0$). When plate **12b** reaches the point ($X=+X_0$, $Y=0$), the radiation is again interrupted by, for example, conditioning the accelerator **104** to provide no electron beam pulses or by closing a shutter to block the electron beam e^-. The first half of the treatment, in which the positions of plates **13**, and **14** are held constant, is complete.

To set up for the second half of the treatment, the upper plate **12a** is returned to ($X=-X_0$, $Y=0$), "fully opening" the upper plates **12a** and **12b**. These plates will be motionless in the second half of the treatment. As in the first half of the treatment, the motionless plates are only opened enough to irradiate the zone to be treated so that surrounding tissues are n t subjected to unnecessary irradiation.

Lower plate **14** is moved to the origin and lower plate **13** is initially left at its open position at ($X=0$, $Y=Y0$). Plate **14** is held motionless at the origin, while Plate **13** is actuated towards plate **14**. During this portion of the treatment, the intensity of the radiation beam is governed by equation (16). The isodose contour has the desired parabolic cross section, with the maximum radiation dosage at the origin, and zero dosage at ($Y=-Y_0$).

Once the two plates meet at the origin, the beam is completely blocked. The irradiation of the half of the treatment area for which Y is less than zero is complete for the second half of the treatment (with X=a constant).

During the last portion of the irradiation, plate **13** is held motionless at the origin, while plate **14** moves away from plate **13** in the positive Y direction. The intensity of the radiation beam during this part of the treatment is again controlled to follow equation (16). The last portion of the irradiation deposits a beam profile on the positive side of the Y axis, completing the desired parabolic cross section, with the maximum radiation dosage at the origin, and zero dosage at ($Y=+Y_0$). When plate **14** reaches the point ($X=0$, $Y=+Y_0$), the radiation is interrupted and the treatment is complete.

A second embodiment of the invention for depositing the desired parabolic isodose profile may be used to overcome hardware limitations on the radiation treatment apparatus which restricts the motion of the lower plates. In the second method, the lower plates may have limited ability to move, or they may even be fixed.

In this embodiment of the invention, the first half of the treatment is performed with the lower plates **13**, **14** fixed, while the intensity of the radiation beam and the motion of plates **12a**, **12b** is defined by equation (15), as in the first embodiment. At the completion of the first half of the treatment, the radiation is interrupted, the upper plates **12a**, **12b** are returned to their original positions, and the lower plates **13**, **14** remain open. The lower part of collimator assembly **105** is rotated ninety degrees by the actuator **22**, responsive to the processor **21**, so that the upper plates **12a**, **12b** are positioned along the Y axis, and the lower plates are symmetrically placed about the X axis. The second half of the treatment follows the beam intensities and plate motions governed by equation (16), as in the first embodiment. In this second half of the treatment, however, it is the plates **12a** and **12b** which are moved.

The second embodiment may have advantages over the first embodiment for a beam forming apparatus which has a rotatable collimator. Because the upper plates are closer to the radiation source, movement of an upper plate effects a greater change in the width of the beam (in the plane of the treatment area) than does movement of a lower plate through the same distance. Since the upper **12a**, **12b** and lower **13**, **14** plates are typically actuated by the same type of equipment, they are each capable of being actuated at the same maximum plate velocity. Therefore, the upper plates **12a**,

12b are capable of increasing or decreasing the width of the beam by a desired amount faster than the lower plates 13, 14 can. In addition, control of the apparatus may be simplified in a system having a rotating collimating assembly, since only one pair of numerically controlled actuators 19 is needed to actuate the one set of plates for this device.

It is understood by practitioners in the field that the particular parabolas defined by equations (12) and (13) are exemplary in nature and that a number of variations are mathematically possible. The use of these parabolic contours, rotationally symmetric about the origin is made to simplify the plate movements used to achieve a number of desired isodose contours. For example, one or both of the parabolic contours could be offset from the origin by a constant displacement. This would require both plates in one or both sets of plates to be capable of crossing the axis. Although this is technically feasible, it may be more practical to move the object being treated and keep the beam center at the origin than to electronically offset the beam profile center.

A third embodiment uses the general teachings of the earlier described embodiments to extend the capabilities of the invention even further. In this embodiment, the collimator 105 does not require a flattening filter 5. Instead, the motions of the collimator plates 12, 13, 14 are controlled to produce a beam profile whose isodose contours are approximately flat. That is to say, any isodose contour will lie in a plane parallel to the treatment surface. Using this method, the radiation output of the electron accelerator is not decreased by filter attenuation, so that for a given accelerator, higher radiation intensity may be applied to the treatment area. This method may have many applications ranging from pencil beam treatment to whole body radiation.

FIG. 4 shows the beam profile 100 produced with both collimator plates open, when the flattening filter 5 is removed (hereinafter referred to as the "raw beam" profile). The raw beam profile 100 may have an arbitrary form, and will vary with the apparatus used. This profile is empirically determined. For typical raw beams, the isodose curve may be approximated by finding a best-fit parabolic curve 102. The parabolic curve 102 is exaggerated in the Figure to clearly distinguish it from the raw beam profile 100. In order to apply a uniform dosage with the raw beam, it is necessary to expose the areas further from the origin to the beam longer than the center is exposed to the beam. That is to say, a compensating beam profile that is complementary to the parabolic isodose curve of the raw beam 100 is needed.

FIG. 5a shows how a compensating isodose curve 110 is added to the raw beam isodose curve 102' to provide a flat profile 114. FIG. 5a shows clearly that the compensating isodose curve 110 is greatest at the edges of the beam 118, and smallest at the beam axis 116. The smallest total flat beam isodose profile achievable is the dose 120 detected at the beam axis 11a for the raw beam isodose curve 102'. Mathematically, the compensating isodose curve 110 is the difference produced by subtracting the raw beam isodose curve 102' from the flat beam curve 114. To produce this compensating beam profile 110, the compensating dosage at the edge of the beam is desirably the raw beam maximum value 120, and the compensating dosage must fall off to zero at the center 11a of the beam. The upper dose limit is determined by the maximum raw beam intensity 120 and the available plate speeds.

It is understood by one skilled in the art that a flat profile with a higher total isodose curve 114' may be achieved by extending the amount of time that the plates spend in any one position.

The desired flat beam profile is defined by $z=F$, where F is constant for any dosage. The raw beam isodose profile is defined by the measured values of $z_r(x,y)$, which are fitted to the form of equation (17). The compensating function $z_c(x,y)$ is the difference of the two.

$$z_r(x,y)=K-a^*(x2+y2) \tag{17}$$

where K is a constant.

The beam attenuation through a solid medium is defined by equation (2). Substituting in the equation for $z_r(x,y)$ yields equation (18).

$$D_{0(x,y)} = D_a e^{\mu[F-K+a(x2+y2)]} \tag{18}$$

Differentiating with respect to time to get the dose rate equation yields equation (19).

$$D_{0(x,y)} = D_a \mu e^{\mu[F-K+a(x2+y2)]} \,|\{2axv_x + 2ayv_y\}| \tag{19}$$

As was done for the first embodiment of the invention, this equation is separated into functions of X only and Y only yielding equations (20) and (21) governing the plate motions.

$$D_{01(x)}|_{y=const.} = D_a \mu [e^{\mu(F-K+ay2)}] * e^{\mu ax2}\, 2axv_x \tag{20}$$

$$D_{02(y)}|_{x=const.} = D_a \mu [e^{\mu(F-K+ax2)}] * e^{\mu ay2}\, 2ayv_y \tag{21}$$

As noted above, in order to move the collimator plates to furnish the beam profile defined by equations (20) and (21), the treatment area must be exposed to the edges of the beam longer than the center of the treatment area (at the beam axis). As shown in FIGS. 2a and 2b, during any dynamic beam forming treatment, the region under the stationary plate is exposed to the more intense radiation.

In contrast to the parabolic beamform generation in the first and second embodiments of the invention, flat beam generation shown in FIG. 5a requires that the stationary plate be stationed at the outer edge of the beam instead of at the beam center. In order to accomplish this, both plates in at least one set of collimator plates 12a, 12b are capable of crossing the axis.

In order to apply the treatment, the apparatus is first set up with the lower collimator plates 13, 14 positioned at edges of the beam field symmetrically placed about the X axis at coordinates ($X=0$, $Y=-Y_0$) and ($X=0$, $Y=+Y_0$), respectively, where Y_0 is a constant. These plates are held steady during the first section of the treatment.

As shown in FIG. 5b, upper plates 12a and 12b are both initially placed along the X axis at ($X=-X_0$, $Y=0$). Plate 12a is held motionless at the edge of the desired beam, while Plate 12b is actuated towards the origin, increasing the width of the beam. During this portion of the treatment, the intensity of the radiation beam is governed by equation (20).

Once plate 12b reaches the origin, the treatment is interrupted. The irradiation of the portion of the treatment area for which X is less than zero and Y is a constant is complete. Next, as shown in FIG. 5c, plate 12a is positioned at the origin and plate 12b is moved to

($X=+X_0$, $Y=0$) before beginning the next portion of the treatment.

During the next portion of the irradiation, plate **12b** is held motionless, while plate **12a** moves towards **12b** in the positive X direction, decreasing the beam width. The intensity of the beam during this part of the treatment is again controlled to follow equati n (20). The second portion of the irradiation deposits a beam profile on the positive side of the X axis, completing the desired flat beam. When plate **12b** reaches the point ($X=+X_0$, $Y=0$), the plates have closed and the radiation is interrupted. The first half of the treatment, in which the positions of plates **13**, and **14** are held constant, is complete. It should be noted that both plates **12a** and **12b** cross the beam axis during the first half of the treatment.

The upper plate **12a** is returned to ($X=-X_0$, $Y=0$), "fully opening" the upper plates. As in the first half of the treatment, the motionless plates are only opened up enough to irradiate the zone to be treated, and surrounding tissues are not subjected to irradiation. Lower plates **13** and **14** are both moved to ($X=0$, $Y=-Y0$) a closed position, prior to beginning the second half of the irradiation.

From this point on, the half of the treatment with the upper plates fixed proceeds in the same manner as the prior treatment when the lower plates were held still. Plate **13** is held motionless at the edge of the beam, while Plate **14** is actuated away from plate **13**. During this portion of the treatment, the intensity of the X ray beam is governed by equation (21). The isodose contour has the desired flat profile.

Once the plate **14** reaches the origin, the treatment is interrupted. The irradiation of the half of the treatment area for which Y is less than zero and X is constant is complete. Plate **13** is moved to the origin and plate **14** is moved to the edge of the beam at ($X=+X_0$, $Y=0$) before resuming treatment.

During the last portion of the irradiation, plate **14** is held motionless, while plate **13** moves towards plate **13** in the positive Y direction. The intensity of the beam during this part of the treatment is again controlled to follow equation (21). The last portion of the irradiation deposits a flat beam profile on the positive side of the Y axis, completing the treatment. The result is that the isodose contour has the desired flat profile.

It is understood by one skilled in the art that a flat profile with a higher total dosage **114'** may be achieved by reducing the velocities v_x and v_y resulting in the plates being held in each position for a longer period of time.

Furthermore, it should be understood by those skilled in the art that other movements of the aperture plates **12a**, **12b**, **13** and **14** could produce the same result. For example, in FIG. 5c, both plates **12a** and **12b** could start at position (0,+X0) and plate **12a** could be moved away from plate **12b**.

A fourth embodiment of the invention produces a flat beam profile using only one pair of movable plates. In the previous embodiment, both plates of the pair are able to be moved across the beam axis. In this fourth method, the lower plates may have limited ability to move, or they may even be fixed.

In this embodiment of the invention, the first half of the treatment is performed with the lower plates **13**, **14** fixed, and the intensity of the radiation beam is defined by equation (20), as in the third embodiment. At the completion of the first half of the treatment, the radiation is interrupted, the upper plates **12a**, **12b** are returned to their original positions while the lower plates **13**, **14** remain open. The lower part of collimator assembly **105** is rotated ninety degrees, so that the upper plates **12a**, **12b** are positioned along the Y axis, and the lower plates are symmetrically placed about the X axis. The second half of the treatment follows the beam intensity and plate motions governed by equation (20), as in the third embodiment.

The fourth embodiment, like the rotationally symmetric beam profile with collimator rotation, may have advantages over moving the lower plates in a system with a rotatable collimator. Since the flat beam generation requires the collimator plates to cross the beam axis, the plate actuating hardware is more complex than for a more general beam profile. It is therefore a distinct advantage to use only one set of movable plates.

It is understood by one skilled in the art that many variations of the embodiments described herein are contemplated. While the invention has been described in terms of exemplary embodiments, it is contemplated that it may be practiced as outlined above with modifications within the spirit and scope of the appended claims.

What is claimed is:

1. A method for applying a desired radiation treatment in a system having: 1) a radiation source which generates a radiation beam having an intensity along an axis and 2) a collimator assembly having a plurality of independently movable sets of plates disposed in the path of the radiation beam and oriented in a direction perpendicular to said beam axis, each set having two movable plates, the method comprising the steps of:
   a) defining a continuous and continuously derivable function to control the intensity of the radiation beam as a function of plate position to achieve said desired radiation treatment having any desired isodose curve and without the use of rotation of the path of said radiation beam;
   b) actuating each of said plates independently during the treatment, at a respective predetermined velocity to cause sad beam to change in width and intensity over time in accordance with said function so as to produce the desired radiation treatment.

2. The method of claim **1**, further comprising the step of positioning both plates such that at least one set of movable plates defines an opening on one side of the beam axis during the treatment.

3. A method for applying a desired radiation treatment with a rotationally symmetric isodose profile in a system having: 1) a radiation source which generates a radiation beam having an intensity along an axis and 2) a collimator assembly having a plurality of sets of independently movable plates disposed in the path of the radiation beam and oriented in a direction perpendicular to said beam axis, each set having two movable plates, the method comprising the steps of:
   a) selecting a set of movable plates;
   b) generating control signals for actuating said selected set of plates;
   c) positioning a first plate in the selected set at the axis and a second plate in the selected set at a predetermined distance form said axis;
   d) actuating said selected set of plates during the treatment, in response to said control signals, causing said beam to change in width, comprising the steps of;
   1) actuating the second plate in the selected set to meet the first plate at the axis;

2) interrupting the radiation when the plates meet;
3) continuing the radiation while actuating the first plate to move away form the second plate;
4) interrupting the treatment when the second plate is separated form the first plate by the predetermined distance;

e) positioning one of said plurality of sets of movable plates for moving in a second direction perpendicular to the first direction; and

f) repeating step (d) for said positioned set of plates.

4. The method set forth in claim 3, in which step (e) comprises the steps of:

returning the plates to their respective starting positions as defined at step c); and

rotating the collimator assembly ninety degrees.

5. The method set forth in claim 3, in which step (e) comprises the steps of:

selecting a further set of movable plates mounted orthogonal to said set of movable plates; and

positioning a first plate in the selected further set at the axis an a second plate in the set at a predetermined distance from said axis.

6. A method for applying radiation treatment with a flat isodose profile in a system having: 1) a radiation source which generates a radiation beam having an intensity along an axis and 2) a collimator having a plurality of sets of independently movable plates disposed in the path of the radiation beam and oriented in a direction perpendicular to said beam axis, each set having two movable plates, the method comprising the steps of:

a) selecting a set of movable plates;

b) generating control signals for actuating said selected set of plates;

c) positioning first and second plates within the selected set together at a starting position a predetermined distance from the beam axis and on a first side of the axis;

d) actuating said selected set of plates during the treatment, in response to said control signals, causing said beam to change in width, comprising the steps of;
1) actuating the first plate in the selected set to move towards the axis;
2) interrupting the radiation when the first plate reaches the axis;
3) positioning the plates to meet at said predetermined distance on a second side of the axis, opposite to the first side;
4) actuating the second plate in the selected set to move towards the axis;
5) interrupting the treatment when the second plate reaches the axis;

e) positioning one of said plurality of sets of movable plates for moving in a second direction perpendicular to the first direction; and

f) repeating step (d) for said positioned set of plates.

7. The method set forth in claim 6, in which step (e) comprises the steps of:

returning the selected plates to the starting position as defined by step b); and

rotating the collimator assembly by ninety degrees.

8. The method set forth in claim 6, in which step (e) comprises the steps of:

selecting a further set of movable plates mounted orthogonal to said set of movable plates; and

positioning plates within the further set as set forth in step b).

9. A method in accordance with claim 6, in which there is a distance between said plates, the method further comprising the step of defining a function to control the intensity of the radiation beam as a function of plate position so that the intensity increase when the distance between the plates decreases.

10. A method for applying a desired radiation treatment with a parabolic isodose profile in a system having: 1) a radiation source which generates a radiation beam having an intensity along an axis and 2) a collimator assembly having at least one st of independently movable plates disposed in the path of the radiation beam and oriented in a direction perpendicular to said beam axis, said set having two plates, the method comprising the steps of:

a) defining a function to control the intensity of the radiation beam as a function of plate position to achieve said desired radiation treatment;

b) positioning a first plate in the set at the axis and a second plate in the set at a predetermined distance from said axis;

c) generating control signals for actuating said set of plates;

d) actuating said set of plates during the treatment, in response to said control signals, causing said beam to change in width, comprising the steps of;
1) actuating the second plate in the set of plates to meet the first plate at the axis;
2) stopping the radiation when the first and second plates meet;
3) restarting the radiation while actuating the first plate to move away form the second plate; and
4) stopping the treatment when the second plate is separated from the first plate by the predetermined distance.

11. A method in accordance with claim 10, in which said first and second plates are moved with a constant velocity during respective steps (1) and (3).

12. A method in accordance with claim 10, in which step (a) includes the step of defining said function to achieve an isodose profile which is continuous and continually derivable.

13. A method in accordance with claim 10, in which there is a distance between said pates and step (a) includes the step of defining said function to increase the radiation beam intensity when the distance between said plates decreases.

14. A method in accordance with claim 10, further comprising the following steps:

returning the plates to their respective starting positions as defined at step (b);

rotating the collimator assembly ninety degrees; and

repeating steps (c) and (d).

15. A method in accordance with claim 10, in which the system includes third and fourth independently movable plates, the method further comprising the following steps:

positioning said third and fourth plates prior to executing step (c), so that each is located at a further predetermined distance from said axis;

positioning the first and second plates within said set after executing step (d), so hat each is located at said predetermined distance from said axis;

positioning the third plate at the axis and the fourth plate at said further predetermined distance form said axis;

actuating said third and fourth plates, in response to said control signals, causing said beam to change in width, comprising the steps of;

1) actuating the fourth pate to meet the third plate at the axis;

2) interrupting the radiation when the third and fourth plates meet;

3) continuing the radiation while actuating the third plate to move away from the fourth plate; and

4) stopping the treatment when the fourth plate is separated from the third plate by said fourth predetermined distance.

16. A method for applying a desired radiation treatment to a predetermined area using a system having: 1) a radiation source which generates a radiation beam having an intensity along an axis and 2) a collimator assembly having a beam flattening filter and at least one set of independently movable plates disposed in the path of the radiation beam and oriented in a direction perpendicular to said beam axis, said set having two movable plates, the method comprising the steps of:

a) defining a function to control at least one of the intensity of the radiation beam and the velocity of said plates to achieve said desired radiation treatment, said treatment having a continuous and continually derivable isodose profile with an inflection point approximately coincident with a center point of the predetermined area;

b) actuating each of said plates in accordance with aid function independently during the treatment, to cause said beam to change in width over time; and

c) controlling said radiation source in accordance with said function to cause said beam to change in intensity over time to produce the desired treatment.

17. A method for applying a desired radiation treatment to a predetermined area using a system having: 1) a radiation source which generates a radiation beam having an intensity along an axis and 2) a collimator assembly having at least one set of independently movable plates disposed in the path of the radiation beam and oriented in a direction perpendicular to said beam axis, said set having two movable plates, the method comprising the steps of:

a) defining a function to control at least one of the intensity of the radiation beam and the velocity of said plates to achieve said desired radiation treatment, said desired radiation treatment having a continuous and continually derivable isodose profile which is at least as great at the edge of the are as in the center of the area;

b) actuating each of said plate sin accordance with said function independently during the treatment, to cause said beam to change in width over time; and

c) controlling said radiation source in accordance with said function to cause said beam to change in intensity over time to produce the desired radiation treatment.

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